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Initial Effects of Prescribed Fire and Mechanical Site Preparation on Seedling Environment and Establishment on a Backlog NSR Site in Central Interior British Columbia

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EXECUTIVE SUMMARY

A substantial amount of the backlog, not satisfactorily restocked (NSR) land in the central interior of British Columbia occurs on sites that were logged to intermediate utilization or other partial cutting standards before about 1970. Many of these sites support stands of residual and naturally regenerated subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Such residual stands are generally considered to be undesirable because trees scarred during logging often develop decay problems, and because subalpine fir is not as productive as interior spruce and lodgepole pine on many sites. These sites are classified as NSR when there is insufficient stocking of healthy, well-spaced trees of an ecologically suitable species. It may be desirable to rehabilitate some of these sites by clearing the residual trees and establishing more productive stands.

A study was initiated in the Prince George Forest District in 1986 to investigate the effects of six preparation regimes on backlog NSR sites which had resulted from partial cutting. The treatment regimes consisted of windrowing, broadcast burning, and herbicide spraying followed by broadcast burning (spray & burning), all with and without subsequent disc-trenching. The effects of these regimes on soil nutrient status, microclimate, and vegetation, and on the establishment of planted interior spruce and lodgepole pine seedlings, were then examined. Fuel consumption as a result of burning and soil disturbance as a result of mechanical site preparation were also assessed.

The fuel consumption assessments revealed that there was a higher percentage of fine slash consumption and more complete fire spread in the spray & burn treatment than in the unsprayed broadcast burn treatment. Fire spread was more strongly correlated with slash cover, and forest floor depth of burn with slash load, in the broadcast burn than in the spray & burn treatment. Extreme temperatures were measured at the soil surface during both burn treatments, but temperatures in the lower forest floor layers and in the mineral soil were not strongly affected by burning.

The nutrient status of the mineral soil was not strongly affected by any of the treatments. However, there were moderate losses of total P, S, and probably N from the forest floor in all treatments, and some increases in the available Ca content in the forest floor in the first year following broadcast burning.

Soil temperatures were greater in the spray & burn than in the windrow treatments at some times of the year, and were generally increased by disc-trenching during the first 2 years following site treatment. There were few apparent differences in soil moisture between treatments, probably because weather conditions were generally moist during the study period, though there was a tendency for the soil in the berms resulting from disc-trenching to dry more quickly than non-trenched soils in dry weather.

In the first two growing seasons following treatment, total vegetation and fireweed cover and volume were lower in the spray & burn than in the burn and the windrow treatments. Vegetation volume following treatment was positively correlated with initial volume in the burn and spray & burn regimes. The growth of planted tree seedlings was generally greater in the spray & burn treatment than in the burn and the windrow treatments. Disc-trenching resulted in increased seedling diameter and in increased foliar and root mass and in a lower shoot/root ratio. Lodgepole pine showed a greater range of growth response to site preparation than did interior spruce.

These preliminary results suggest that spray & burning should be considered among potential treatment options for rehabilitation of similar sites, where it can be practicably used. Broadcast burning and windrowing alone may be more suitable treatments for partially cut sites with lower vegetation competition potential.

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INTRODUCTION

A substantial proportion of the not satisfactorily restocked (NSR) land in the central interior of British Columbia occurs on sites that were logged to intermediate utilization or other partial cutting standards before about 1970.

Though many of these sites support stands dominated by residual and naturally regenerated subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), they may be classified as NSR if they are insufficiently stocked with healthy, well-spaced trees of an ecologically suitable species. Natural regeneration in partially cut stands is often poorly distributed; residual stems may contain decay as a result of injury during logging; and subalpine fir, on certain sites, is not a suitable species. Thus, to establish full stocking of desirable species, it may be necessary on many sites to clear the residual trees, prepare the site, and plant with appropriate stock.

This study was initiated in 1986 to investigate the effectiveness of treatment regimes for regenerating partially cut backlog sites with lodgepole pine (*Pinus contorta* Dougl.) and interior spruce (*Picea glauca* (Moench) Voss × *engelmannii* Parry ex Engelm.) following removal of the residual stand. Six treatment regimes were examined: windrowing, broadcast burning, and herbicide spraying followed by broadcast burning, with and without disc-trenching. Pine and spruce seedlings were subsequently planted in each regime.

This report summarizes the initial effects of the six regimes on seedling establishment, vegetation, soil nutrient status, and soil microclimate in the first 2 years following planting. The fuel load and consumption resulting from broadcast burning and the soil disturbance resulting from mechanical site preparation are also reported. Further vegetation and seedling assessments will be required to determine the effectiveness of the treatment regimes in establishing free-growing plantations.

The microclimate data set was not complete at the time this report was written. A more complete analysis of these data will be given in a future report.

STUDY SITE

The study was located near Stony Lake in the Prince George Forest District (Fig. 1) within the Sub-Boreal Spruce biogeoclimatic zone, moist cool subzone (SBSwk), at an elevation of 960 m. The soils on the study site were derived from glacial till and are medium textured and moderately well drained. The site was classified in the Hybrid spruce–oak fern site series (SBS wk/01) (D. Meidinger, pers. comm.), and has a predominantly mesic moisture regime.

The study site is within a 400-ha block that was partially logged in 1968–1970. The residual trees left after logging were primarily subalpine fir. These were not uniformly distributed, occurring in small groups and strips and as single stems. Following a regeneration survey in 1984, the block was classified as NSR. Some characteristics of the residual stand are given in Table 1.

The cover and distribution of shrubs and herbs were also not uniform across the study site. There was a dense cover of shrubs and herbs — primarily black twinberry (*Lonicera involucrata* (Richards.) Banks ex Spring), thimbleberry (*Rubus parviflorus* (Nutt.)), and fireweed (*Epilobium angustifolium* L.) — in the openings

TABLE 1. Residual stand characteristics (stems > 7.0 cm dbh)

Average diameter (cm)	Average height (m)	Average stem volume (m^3)[a]	Total stand volume (m^3/ha)[a]	Merchantable stand volume (m^3/ha)[a]	Stand density (stems/ha)
15.4	8.6	0.12	36.9	28.8	306

[a] Estimated from the B.C. Forest Service (1976) "Whole stem cubic metre volume equations and tables." Merchantable volume based on a 25 cm tall stump and a 10 cm diameter top.

between clumps of residual trees. Within the clumps of residual trees the shrub cover was lower, the vegetation consisting primarily of bunchberry (*Cornus canadensis* L.), five-leaved bramble (*Rubus pedatus* Sm.), and feathermosses.

METHODS

Experimental Design

The trial consisted of a complete factorial with three primary treatments (broadcast burn, spray & burn, and windrow), two secondary treatments (no treatment and disc-trench), and two species (interior spruce and lodgepole pine) of planting stock yielding 12 ($3 \times 2 \times 2$) treatment combinations. The treatments were applied in a split-split plot design with primary site preparation treatments as main-plot factors, and disc-trenching and tree species as sub-plot factors, and was replicated 3 times. A 30×33 m permanent sample plot (PSP) was established in each of the 36 sub-plots. The treatment layout is shown in Figure 2. In the windrow treatment, the PSPs were located between windrows. The areas where the windrows were located and subsequently burned were not sampled.

Treatment Methods

All stems over 1.5 m height in the residual stand were hand-felled in March 1987, to facilitate site preparation and planting. Windrowing was carried out in June 1987 with a brush blade mounted on an International TD-15C crawler tractor. Slash was piled in windrows outside the subplots and burned the following November. The herbicide Vision® (containing the active ingredient glyphosate) was also applied in June 1987, by backpack sprayer at a nominal rate of 2.1 kg active ingredient/ha (6 L product per hectare) in a volume of approximately 250 L solution/ha.

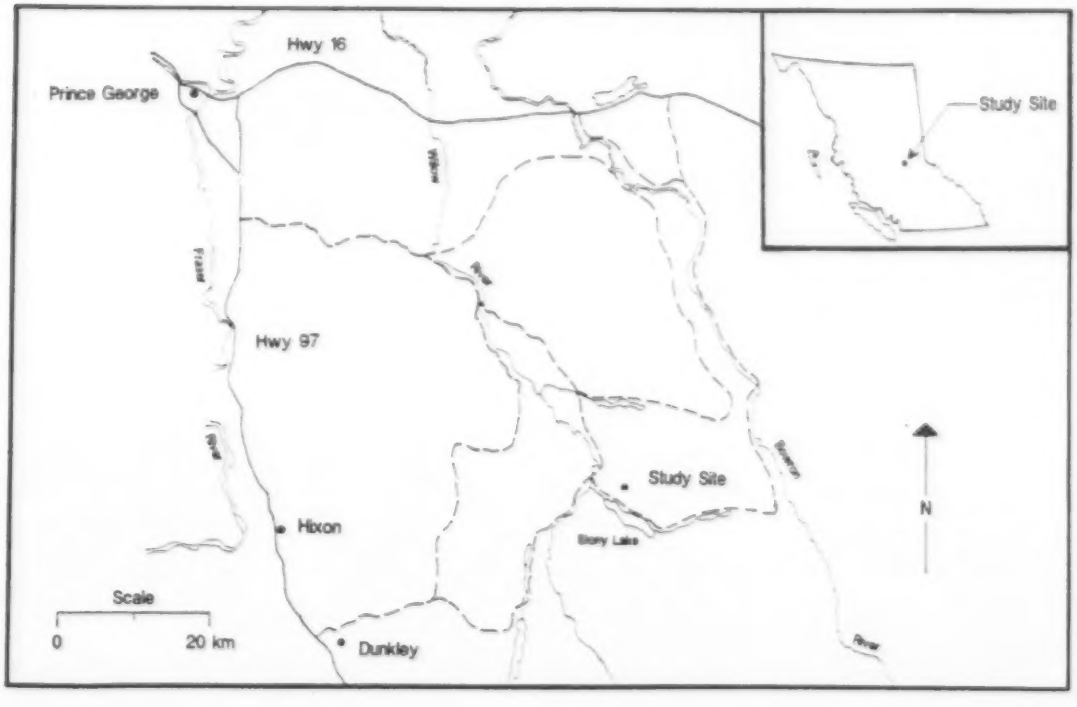

FIGURE 1. Study site location.

FIGURE 2. Treatment layout.

Broadcast burning was carried out on September 7, 1987 between 16:00–18:00 LST. Three blocks (consisting of a pair of sprayed and non-sprayed areas) were ignited individually by a helicopter equipped with a drip torch and gelled fuel. Temperature, relative humidity, wind speed and direction, and total rainfall were measured daily at noon for 4 months before burning. These observations were used to calculate the codes and indices of the Canadian Forest Fire Weather Index (FWI) System (Stocks *et al.* 1989). Ambient weather conditions and FWI System values on the day of ignition are given in Appendix 1.

Disc-trenching was carried out in October 1987 with a TTS-Delta powered disc-trencher mounted on a rubber-tired skidder.

Container-grown interior spruce and lodgepole pine seedlings were planted in May 1988. The seedlings were grown in Prince George, lifted in November 1987, and kept in cold-storage until they were transported to the site immediately before planting. Seedling stock types, seedlots, root growth capacity values, and physical characteristics are given in Appendix 2. Each PSP was planted with 110 seedlings at 3 m square spacing (1100 stems per hectare) with one surrounding buffer row. An additional 25 seedlings were planted adjacent to each PSP for biomass sampling. Soon after planting, some lodgepole pine seedlings were found to have been clipped by snowshoe hares. A 40 cm plastic mesh (Protex®) tube was then placed over each of the pine seedlings in the PSPs to prevent further damage. The tubes were removed 2 years after planting.

Sampling Methods and Calculations

Fuel and fire characteristics

To characterize treatment severity and examine the effect of site conditions on treatment parameters, slash and forest floor moisture before broadcast burning, slash consumption and forest floor depth reduction resulting from burning, and soil temperatures during burning were measured.

Woody fuel load and consumption as a result of burning were determined in each of the PSPs in the burn and the spray & burn treatments. The line intersect technique was used for this, following a modified methodology of Trowbridge *et al.* (1986). Fuels were measured before and after burning in two large

randomly oriented fuel sampling triangles (30 × 30 × 30 m and 15 × 15 × 15 m) superimposed on each PSP, and in five small triangles (2.6 × 2.6 × 2.6 m) randomly located within each PSP. Slash samples representing each tree species and size class present were collected for relative density determinations, which are given in Appendix 3.

Vegetation biomass was determined by destructive sampling in three additional 0.5-m^2 quadrats located 2 m outside the large fuel sampling triangles perpendicular to the midpoint of each leg. Vegetation biomass after burning was estimated as the product of initial load and proportion of the area burned, as the vegetation was completely consumed in the burned areas. Slash loads were calculated with the use of a BASIC program on file at Pacific Forestry Centre.

Forest floor depth reduction as a result of burning (including litter and moss layers), and the forest floor depth remaining after burning, were measured with depth-of-burn pins at 30 points along the sides of the large triangles and 7 points along the sides of each of the small triangles. Forest floor mass sampling is described in the "Soil Nutrient Status" section, which follows. Mineral soil exposure before and after burning was measured along each transect, and percentage exposure was calculated as length of exposed soil per total transect length × 100. The percentage of area burned was determined in a similar manner.

Surface and soil temperatures during burning were measured in 30 of the 60 small fuel triangles in the burn treatments with the use of a specialized datalogger (thermologger) developed by Forest Technology Systems Ltd. Each thermologger recorded temperatures during burning from three high-temperature thermocouples fixed 2 cm above the forest floor, and 3 cm and 7 cm below the forest floor surface.

The moisture content of the slash, vegetation, and litter in the sprayed and unsprayed treatments was determined by gravimetric sampling on the burn day. A forest floor sample was taken for moisture determination adjacent to each of the thermologgers on the day before burning.

In a companion study by Lawson and Hawkes (1989), seasonal trends (May–September) in the moisture content of slash and the forest floor were examined during the first 2 years following knockdown of the residual stand. Their methods are described by Taylor *et al.* (1989).[1] Some of these results are also reported here because they have implications for burn timing.

Soil disturbance

The amount of soil disturbance caused by windrowing was measured along three 15-m transects in each of the 12 windrowed PSPs. Each disturbed area was classified as light, scalped, buried, or mixed. Light disturbance was defined as a condition where the forest floor was still in place but had been cut or compressed by the bulldozer pads. Scalped, buried, and mixed types were defined as conditions where the forest floor was removed and mineral soil exposed; where mineral soil covered the forest floor; and where the forest floor was mixed with the mineral soil, respectively.

The dimensions and area occupied by the berms and the trenches created by disc-trenching were assessed along a 30-m transect in 6 of the 18 disc-trenched PSPs. The transects were located perpendicular to the direction of machine travel at a random distance along the direction of travel. The height and width of berms, depth and width of trenches, inter-trench distance, and inter-berm distance were measured along each transect.

Soil nutrient status

Soil sampling was carried out before and after site preparation in June of 1987 and 1988, respectively. Forest floor samples (L,F,H layers) were collected for mass and nutrient concentration determinations from four 25 × 25 cm quadrats in each PSP at each sampling date. Only in the disc-trenched plots in 1988 was the forest floor not sampled. However, because of high spatial variability in forest floor depth, the

[1] Taylor, S.W., B.C. Hawkes, R.H. Silversides, M.G. Weber, and B.D. Lawson. 1989. Prescribed fire effects and efficacy in the treatment of backlog NSR land in Northern interior B.C. FRDA Project 1.20. Unpub. Establishment Rep.

values of forest floor mass in some PSPs were greater after treatment than before, which is not plausible. Therefore, forest floor mass following burning was calculated for each plot as the product of mean pre-treatment mass and mean forest floor depth-of-burn, divided by mean pre-burn forest floor depth. Forest floor mass following windrowing was calculated for each plot as: mean pre-treatment mass × (1 – [% scalped area/100]).

Bulk samples of the surface mineral soil layer (0–15 cm) were collected before site preparation from four and two of the sample points in each PSP, for nutrient concentration and bulk density determinations, respectively. An identical procedure was used the following year, except that in the disc-trenched plots bulk samples of the 0–15 cm material were taken from the shoulder of the berms because this was where most of the seedlings were planted.

Total N, C, P, S, K, Mg, Ca, exchangeable K, Mg, and Ca, and extractable NH_4^+ and NO_3^- were determined for the forest floor samples. Total N, C, P, and S, exchangeable K, Mg, and Ca, and extractable NH_4^+ and NO_3^- were determined for the mineral soil samples, though only the N results for the mineral soil are reported here. The samples used for the extractable N determinations were frozen between collection and chemical analysis. Soil nutrient contents were calculated as the product of nutrient concentrations and soil mass. Mineral soil bulk densities are given in Appendix 4.

Microclimate

The microclimate measurement program consisted of continuous monitoring of some variables by automated instrumentation, supplemented by a program of intensive spot measurements carried out several times throughout the growing season to improve the spatial replication of the data for statistical analysis procedures. Standard weather observations were also recorded at the site over a 3-year period (August 1986–September 1989) to characterize the background climate.

1. Continuous monitoring

Air temperature, and soil temperature and moisture in the rooting zone, were continuously monitored in the spray & burn and the windrow treatments, with and without disc-trenching, beginning in May 1988. Each of these four treatment regimes was instrumented with type UUT51J1 thermistors and Delmhorst Model 112-GB-1 soil moisture blocks in an independent micrologger based system. Installations were located in each of the three replicate PSPs across the blocks (12 locations). The non-sprayed broadcast burn treatments were not included because of equipment limitations.

At each location, air temperature at 10 cm above the surface was measured by a thermistor housed in a sandwich screen. Seedling temperature was inferred from an analog consisting of a thermistor inserted and potted with epoxy mid-way inside a white PVC tube (20 cm long by 0.48 cm outside diameter and 0.24 cm inside diameter). The seedling analog was placed vertically into the ground so that the thermistor at the mid-point of the analog was flush with the surface of the ground. However, air and seedling analog temperatures are not reported here.

In the spray & burn and the windrow treatments, thermistors were installed at 0.5 cm below the top of the forest floor, at the interface between the forest floor and mineral soil, and at 10 cm and 20 cm below the interface. Moisture blocks were located at the 10 and 20 cm levels below the interface.

In the two disc-trenched treatments, sensors were set in a vertical profile on the east side of the berm, halfway between the ridge and the foot of the berm. The berm condition was manually modified to an idealized but representative condition, with a surface mineral capping and an inverted forest floor over intact forest floor and mineral soil. Thermistors were placed at 0.5 cm below the surface, at the interface between the undisturbed and the overturned organic layers, at the interface between undisturbed forest floor and mineral soil, and at 10 cm below the interface. Moisture blocks were located in the middle of the organic layers and at the 10 cm level below the interface.

Data were collected with the use of PFC multiplexers and Campbell CR21 and CR21X dataloggers. During 1988 and early 1989, the loggers recorded statistics hourly during the growing season and every 4 hours during the winter. Soil temperature and moisture were sampled at the end of the recording interval;

average and extreme values over the interval were recorded for air and seedling analog temperatures. In July 1989, the multiplexers were abandoned and the number of variables monitored was reduced; 10-cm moisture, and temperatures at the surface, interface and 10-cm depth were measured at all sites for the remainder of the study period.

2. Spot sampling

Spot measurements of soil temperature and moisture were carried out in each of three replicate PSPs in the spray & burn, windrow, and windrow and disc-trench treatment regimes on four occasions during 1988 and three occasions during 1989. Early morning (6 a.m.) soil temperature and moisture were measured at fixed locations with thermocouples and thermocouple psychrometers, moisture blocks, and tensiometers. Measurements were made at similar depths as the continuous measurements at 9 locations within a plot. In the spray & burn and the windrow treatments, sensors were located in screefed planting spots containing seedlings. The installations in the windrow and disc-trench regime were located on the sides of berms with an eastern exposure. The pre-dawn (3–5 a.m.) water potential of three tree seedlings within each plot was determined at each occasion. In 1988, the water potential of fireweed and twinberry plants in an untreated area was also determined, and in 1989 the water potential of three fireweed and three thimbleberry plants was determined within each plot.

Vegetation

The mean height and total cover of each vascular plant species, and the mean canopy height and total vegetation cover, were estimated within a 3 m diameter circular quadrat at 10 randomly located seedling-centred permanent points in each PSP (360 in total). In the broadcast burn and the spray & burn treatments, the vegetation quadrat, small fuel triangle, and thermologger locations were coincident. The assessments were carried out only in the broadcast burn and the spray & burn treatments in July 1987 (pre-burn), and in all the treatments in July 1988 and July 1989 (post-treatment). The volume (m^3 per m^2) of each plant species was calculated as the product of cover (%) and height (cm) divided by 10 000. The density and basal area of the residual stand before knockdown was estimated from stump measurements in each PSP.

Seedling establishment

The total height, height increment, basal diameter, and condition of each seedling in the growth assessment plots were assessed at the end of the first two growing seasons (September of 1988 and 1989). Seedling volume index was calculated (assuming a conical form) as the product of basal area and height divided by 3. Three randomly selected seedlings adjacent to each PSP were excavated at the end of each growing season (108 in total) and separated into eight components for mass determination: roots; terminal bud; leader needles and wood; current year lateral branch needles and wood; and the previous year's stem and branch wood, and needles. Seedling biomass samples were retained for total N, P, S, K, Mg, Ca, Fe, Cu, and Mn determinations. The current and previous years' needles and stemwood, and root samples from each plot were bulked for analysis, though only current year foliar macro-nutrient concentrations are reported here. The mass and nutrient content of these five seedling components was also determined on a representative sample of seedlings before planting.

Laboratory Analysis

Forest floor and mineral soil mass samples were air-dried and a subsample was oven-dried at 90°C. Seedling biomass samples were oven-dried at 70°C. Samples for nutrient analyses were ground to pass a 2-mm sieve. Subsamples for N, C, and S combustion analyses were further ground to 100 mesh. Chemical analyses were carried out in the Chemical Services Lab at the Pacific Forestry Centre with the following methods:

Total P	H_2O_2/H_2SO_4 digestion with Autoanalyzer colorometric detection
Total N	Leco FP228 Organic Nitrogen Determinator (combustion with thermo-conductivity detection)

Total K, Ca, Mg	H_2O_2/H_2SO_4 digestion with Atomic Absorption (AA) analysis
NH_4^+, NO_3^-	2N KCl extraction with Autoanalyzer colorometric detection
Total C , S	Leco CR12 Carbon and SC132 Sulfur analyzers (combustion with infra-red detection)
Available K, Mg, Ca	10% Na-OAc extraction at pH 4.8 followed by AA analysis.

Statistical Analysis

All statistical analyses were performed with the statistical facility SAS (SAS Institute 1985). Differences between fire impacts on the burn and the spray & burn treatments, and between disc-trenching impacts on the burn and windrow treatments, were distinguished through t-tests. Simple correlation procedures were used to test the significance of associations between: FWI System values and fuel moisture; slash and forest floor consumption variables; fuel consumption and soil temperature variables during burning; vegetation response and initial volume; and vegetation response and fire impact variables determined in the small plots.

Soil temperature and moisture spot sample treatment regime means for each sampling time were compared using a Least Significant Difference procedure. Initial results indicated that there were significant temperature differences between blocks. In particular, temperatures in plot 32 (spray & burn) were significantly different from the other replicates in this treatment. This plot was consequently dropped from the subsequent soil temperature analysis of variance (ANOVA) and an unbalanced design was employed.

An ANOVA, General Linear Model (GLM) procedure was used to test the significance of the main site preparation and disc-trenching treatment effects and interactions on the soil and vegetation variables for each sampling time. Treatment means were distinguished with the use of Student-Neuman-Keuls (SNK) multiple range tests at $p \leq 0.05$. To test the significance of differences between soil nutrient levels before and after treatment, a least squares means test was applied on plot means. Vegetation cover data were transformed through an arcsin (square root) function before analysis, so that the homogeneity of residual variances could be increased. As well, ANOVA GLM procedures were used to test main treatment, disc-trenching, and species effects and interactions on seedling performance variables; and SNK multiple range tests were used to distinguish between treatment means at each sampling time.

Complete ANOVA tables are not given here because of the large number of variables examined (106). Instead, the results of the subsequent multiple range tests are given. In all cases where a significant difference between treatment means appeared at a particular p value, the ANOVA indicated a significant treatment effect at the corresponding level.

RESULTS AND DISCUSSION

Fuel and Fire Characteristics

Fuel load

The fuel load in the burn and in the spray & burn treatments is summarized in Table 2. Fresh, knocked-down subalpine fir stems made up about 55–60 % of the total fine and medium fuel load (≤ 7.0 cm diam.) but only about 30% of the large (> 7.0 cm diam.) woody fuel; the remainder of the material in the 2 classes was vegetation, and old, dead and down material, respectively. Most of the needles on the subalpine fir were retained on the branches up to the time of burning.

Total slash and vegetation load varied substantially between plots, probably because of the variation in the density and crown closure of the residual stand. This observation is supported by significant positive correlations between ≤ 7 cm slash load and the basal area and density of the residual stand ($r = 0.53$ and 0.57; $p < 0.05$). The total slash loads found in this study are within the range of values for recently logged spruce–balsam sites in central interior British Columbia reported by Lawson and Taylor (1986). However,

the fine and medium slash in the present study was less well distributed than would be expected on recently logged areas, because it was composed of undisturbed whole trees, and there was more vegetation present.

TABLE 2. Summary of fuel load and fuel consumption due to burning

	Broadcast burn			Spray & burn			
	Pre[1]	Consumption		Pre	Consumption		n
Vegetation load (t/ha)	6.79	6.11	(90)[2]	8.68	8.68	(100)	36
Slash load (t/ha)							
≤ 7.0 cm	12.60	9.64	(75)a	10.33	9.44	(91)b	12
> 7.0 cm sound	18.37	2.99	(16)a	21.58	3.49	(16)a	12
> 7.0 cm dead/down	37.48	7.82	(21)a	50.22	12.90	(26)a	12
total	68.46	20.45	(30)a	82.13	25.82	(31)a	12
Forest floor mass (t/ha)	39.47	8.07	(21)a	39.38	8.36	(21)a	12
Total organic matter (t/ha)	114.72	34.63	(30)a	130.19	42.86	(33)a	12
Forest floor depth (cm)	9.2	1.9	(21)a	9.6	1.9	(21)a	360

[1] Pre-treatment values.
[2] Values in parentheses are percentage consumption; values in the same row followed by the same letter are not significantly different at $p < 0.05$ according to t-tests.

Fuel moisture content and codes

Trends in the moisture content of subalpine fir slash in the first year following knockdown (determined by repeated weighing of the same pieces) are shown in Figure 3. The drying rate appeared to be inversely related to diameter. Some of the irregular peaks in this figure are because of missing data for some periods. The moisture content of the fine slash (≤ 1.0 cm) was strongly correlated with the Fine Fuel

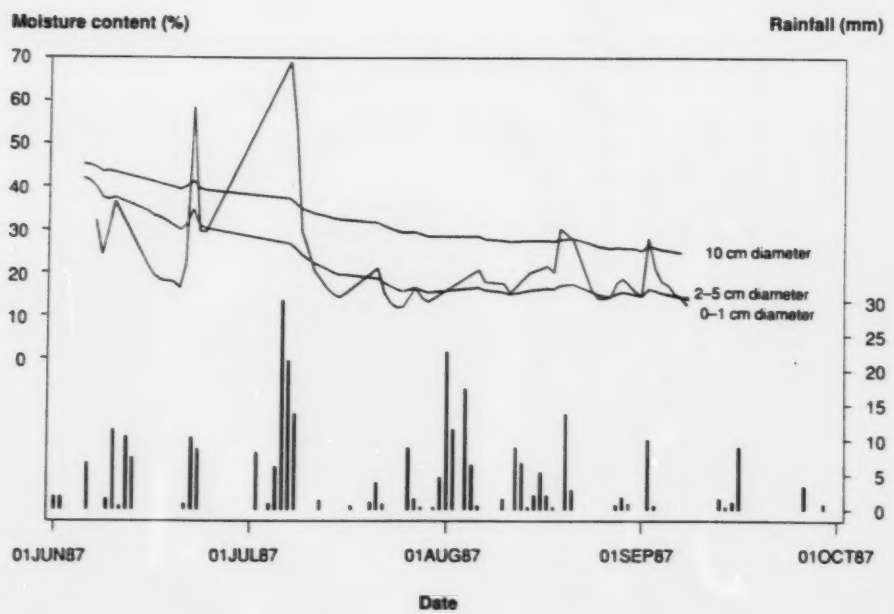

FIGURE 3. Trends in the moisture content of fine, medium, and large diameter subalpine fir slash in the first year following knowdown in relation to precipitation.

Moisture Code (FFMC) of the FWI System in the first two growing seasons (R^2 = 0.69 and 0.87, respectively; $p < 0.05$). The moisture contents of medium diameter (2.0–5.0 cm) and large (10 cm) diameter pieces were not well represented by any of the moisture codes of the FWI System in the first year. In the second year, however, medium subalpine fir and spruce slash moisture were significantly correlated with FFMC (R^2 = 0.40 and 0.52 for fir and spruce, respectively) and Duff Moisture Code (DMC) (R^2 = 0.29 and 0.45 for fir and spruce, respectively). Fuel moisture relationships were discussed in greater detail by Lawson and Hawkes (1990).

The rate and amount of browning of vegetation in the spray & burn treatment appeared to vary between plant species. Most of the twinberry and fireweed were brown by about 6–8 weeks following herbicide application in June, but the thimbleberry was only partially brown by the time of burning, 12 weeks after treatment.

Table 3 shows the moisture contents of the fine slash, live and dead vegetation, and litter on the burn day, and of the forest floor on the previous day, in the burn and the spray & burn treatments. Woody fuel moisture did not appear to be influenced by the herbicide treatment. The moisture content was much lower in the dead than in the live vegetation in both sprayed and non-sprayed treatments; and a higher proportion of the vegetation in the sprayed than in the non-sprayed treatment was dead. The moisture content of dead fireweed in the sprayed treatment was also lower in the sprayed than in the unsprayed treatment, probably because it was killed earlier in the year and had a longer curing period. There were no significant differences ($p \leq 0.05$) in forest floor moisture contents between the sprayed and non-sprayed treatments. Table 3 also suggests that there were no apparent differences in surface litter moisture between treatments, although litter moisture content was much higher at shaded than at exposed locations, and a higher proportion of the non-sprayed area was shaded by vegetation.

The FWI System values during the burning period were: FFMC 89–90, DMC 25, DC 235, ISI 5–8, BUI 40, and FWI 12–17. The ranges for FFMC, ISI, and FWI reflect the diurnal variation in fine fuel moisture and wind speed. Weather observations are given in Appendix 1.

Fire spread and fuel consumption

Fire spread was complete in all of the plots in the spray & burn treatment, but incomplete in some of the plots in the broadcast burn treatment. The reason was probably because of greater browning of the vegetation and exposure of forest floor in the sprayed treatment. The non-sprayed plots where fire spread was complete had greater than 25–30% cover of fine and medium slash. The greater spread potential on sprayed sites may allow for burning under lower fire danger conditions.

Fuel consumption in the burn and the spray & burn treatments is compared in Table 2. Percentage consumption was greater than 95% for the ≤ 1.0 cm diameter slash in both treatments and decreased with increasing diameter. In the > 7.0 cm diameter material, percent consumption of the sound slash resulting from knockdown of the residual stand was somewhat lower than percent consumption of dead and down material. Consumption (%) of ≤ 7.0 cm slash and > 7.0 cm dead and down slash was significantly greater ($p < 0.05$) in the spray & burn treatment than in the burn treatment.

TABLE 3. Moisture content (%) of fuel components before ignition[1]

	Slash (by cm diam. class)		Vegetation						Forestfloor (by cm depth)	
			Fireweed		Twinberry		Litter			
Treatment	0–1	1–3	Live	Dead	Live	Dead	Exposed	Shaded	0–3	3–7
Broadcast burn	12	22	218	109	103	10	7	52	95a[2]	193a
Spray & burn	12	18	—	11	—	11	7	47	101a	181a

[1] All materials were sampled in the afternoon immmediately before ignition except for the forest floor, which was sampled the previous day.

[2] Means within columns followed by the same letter are not significantly different at $p < 0.05$ according to t-tests; n = 3, 3, 3, and 15 for the slash, vegetation, litter, and forest floor components, respectively.

There were no significant differences ($p \leq 0.05$) in forest floor mass consumption or depth reduction between the sprayed and non-sprayed treatments. Depth reduction was moderate (2 cm or 20%), probably because of the high forest floor moisture content on the burn day. In the large non-sprayed plots, forest floor depth of burn was significantly correlated ($r = 0.66$; $p < 0.05$) with consumption of > 7.0 cm slash, likely because of the greater surface heating with increasing slash consumption. Little mineral soil exposure (< 5%) occurred in either burn treatment.

In calculating forest floor mass consumption in this study, it was assumed that forest floor bulk density is uniform with depth. The nominal bulk density derived in this study was 43 kg/m^3. This amount is close to the density for the 0- to 2-cm layer found from limited bulk density sampling on the study area stratified by depth, but is probably too low for the forest floor as a whole. Thus, it appears that the estimates of forest floor mass consumption are reasonable, although initial forest floor mass was underestimated and percent mass loss overestimated. Forest floor depth may have been overestimated, but this is less likely because of the greater sampling intensity. More accurate mass loss determinations might be made from forest floor depth and depth-of-burn measurements, and from a greater number of forest floor bulk density measurements stratified by depth.

In practical terms, the differences in spread and consumption between the burn and the spray & burn treatments in this case were not significant, because both treatments provided improved access for planting and more than the required number of plantable spots to meet the target seedling spacing.

Soil temperatures during burning

Average temperature histories for the spray & burn, and the broadcast burn treatments are shown in Figures 4 and 5. Maximum soil temperatures during burning and the duration that the temperature exceeded 60°C (which is believed to be lethal for plants) are given in Table 4. There were few apparent differences between the burn and the spray & burn treatments in temperature maxima, or in the duration that temperatures exceeded 60°C. This is consistent with the similarity in fuel consumption and forest floor depth reduction found between these treatments. The maximum temperatures were sufficient to kill above-ground plant parts in most locations, and below-ground plant parts at 3 cm and 7 cm depths in about 20 and 3% of the locations, respectively. Similar maximum surface temperature values were found by Vasander and Lindholm (1985) in prescribed fires in Finland with much lower fuel load and consumption.

Maximum temperatures at the 3 cm depth were significantly correlated with total slash consumption, forest floor depth of burn, and the duration that the surface temperature exceeded 500°C which is near the threshold for flaming combustion ($r = 0.35$, 0.36, and 0.63, respectively; $p < .05$). The duration that temperature exceeded 60°C at the 3 cm depth was also significantly correlated with these three variables ($r = 0.35$, 0.40, and 0.62, respectively; $p < .05$). This suggests that in moist forest floors the occurrence

TABLE 4. Summary of peak temperatures during burning and the frequency and duration that temperature exceeded 60°C

	Broadcast burn[a]				Spray & burn			
	Mean	Max.	Min.	Freq. (%)	Mean	Max.	Min.	Freq. (%)
				Peak temperature (°C)				
2 cm above surface	734	989	297	—	703	838	89	—
3 cm below surface	46	108	15[b]	—	37	153	15[b]	—
7 cm below surface	23	54	10[b]	—	21	44	10[b]	—
				Duration > 60°C (min.)				
2 cm above surface	22.1	54.1	8.8	90	19.5	45.7	6.3	90
3 cm below surface	5.1	29.0	0.0	22	3.1	39.0	0.0	22
7 cm below surface	—	—	—	0	—	—	—	0

[a] n = 13 and 15 for the burn and the spray & burn treatments, respectively.
[b] Ambient temperature.

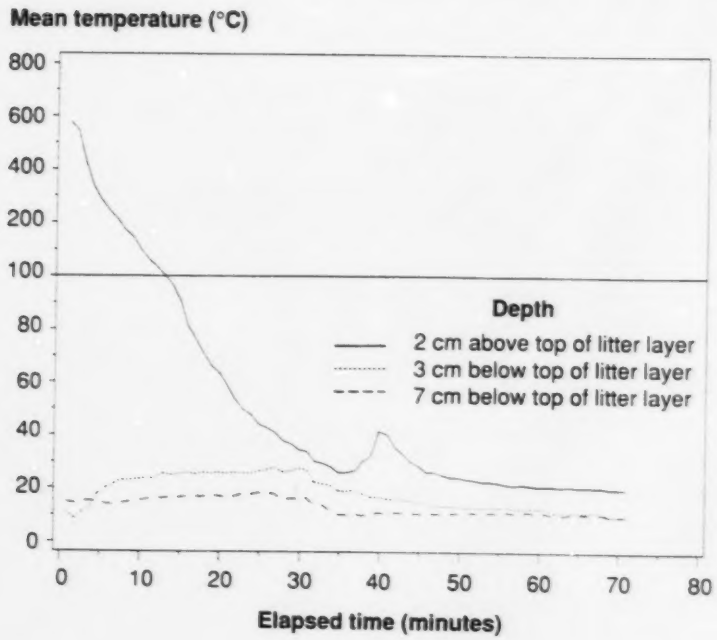

FIGURE 4. Average temperature history in the broadcast burn treatment.

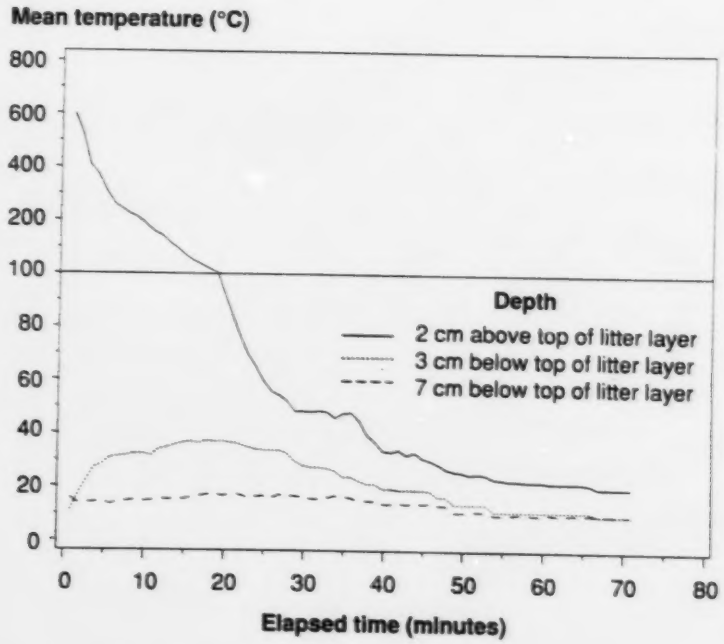

FIGURE 5. Average temperature history in the spray & burn treatment.

and duration of biolethal temperatures are related to the duration of surface heating, which in turn is related to the amount of slash and forest floor consumption. Maximum temperatures in the forest floor decreased with depth and did not increase much above the ambient value at 7 cm below the surface.

The temperature histories for the two individual locations shown in Figures 6 and 7 illustrate the effect of fuel consumption and soil moisture on soil temperature. At a site with 0.5 cm depth of burn (Fig. 6), soil temperature changed very little at 3 and 7 cm during burning, despite extreme surface temperatures. However, at a site with 4 cm depth of burn (Fig. 7), the temperature at 3 cm rose to 90°C about 10 minutes after ignition, then to about 150°C after about 15 minutes. This suggests that the temperature in a moist forest floor during burning may be limited to a 100°C threshold until all the water is driven off, when greater heating or combustion can occur (the thermocouples have an error of ±10°). In a laboratory study, Frandsen and Ryan (1986) also found that temperatures in wet sand 4 cm below a burning fuel bed were limited to about 80°C, despite the much greater fuel consumption that occurred in that study than in this one.

Soil Disturbance

The windrowing treatment in this study resulted in moderate soil disturbance. Mean values of 42, 8, 1, and 2% for light, scalped, buried, and mixed disturbance types, respectively, (53% in total) were found between windrows. The amount of scalping appeared to increase with slash load. This is probably because more machine passes per unit area were required to clear heavy slash concentrations.

The berms and trenches resulting from disc-trenching occupied approximately 28 and 20% of the total treated area, respectively, at an average inter-pass distance of 0.8 m, with 2.0 m between trenches of the same pass. The dimensions of the berm and trench profiles were very similar between the burn and windrow treatments, though berm height was significantly greater in the windrowed than in the burned areas (Table 5). The berms and trenches appeared to be less continuous in the burned than in the cleared areas as well, probably because the disc-trencher tended to ride up over the large logs that remained in the burned areas, causing misses. However, the trenches were clean of debris and the number of plantable spots on the shoulders of the berms was more than adequate to achieve the target seedling spacing in all the treatments. There were also about 300 spots per hectare on the tops of the berms that were considered plantable. Acceptable micro-sites on the tops of the berms consisted of a mineral soil capping over forest floor, or inverted forest floor with a mineral soil capping, which did not contain debris or air pockets.

In this study, mineral soil (0–15 cm) bulk density was significantly greater ($p \leq 0.05$) in the berm shoulders than in undisturbed soils before treatment, but did not appear to be influenced by broadcast burning or by windrowing (Appendices 4 and 5). Blackwell *et al.*,[2] however, found increases in bulk density both within and between windrows, created during rehabilitation of dense lodgepole pine stands. These they attributed to

TABLE 5. Height, width, depth, and spacing of disc-trenched features (m) on the windrow and the burn treatments

		Berm			Trench	
Primary treatment	Inter-pass distance[1]	Height	Width	Inter-row distance[2]	Depth	Width
Windrow	.76a[3]	.22b	.75a	1.96a	.21a	.54a
Burn/spray & burn	.99a	.18a	.71a	1.87a	.19a	.53a
n	36	72	72	36	72	72

[1] Inter-pass distance: spacing between consecutive passes.
[2] Inter-row distance: spacing beteen trenches of the same pass.
[3] Means within columns followed by the same letter are not significantly different at $p < 0.05$ according to t-tests.

[2] Blackwell, B., M.C. Feller, and R. Trowbridge. 1989. Some ecological effects of windrow and broadcast burning on dense lodgepole pine stands. FRDA Project 1.13. Unpubl. Final Rep.

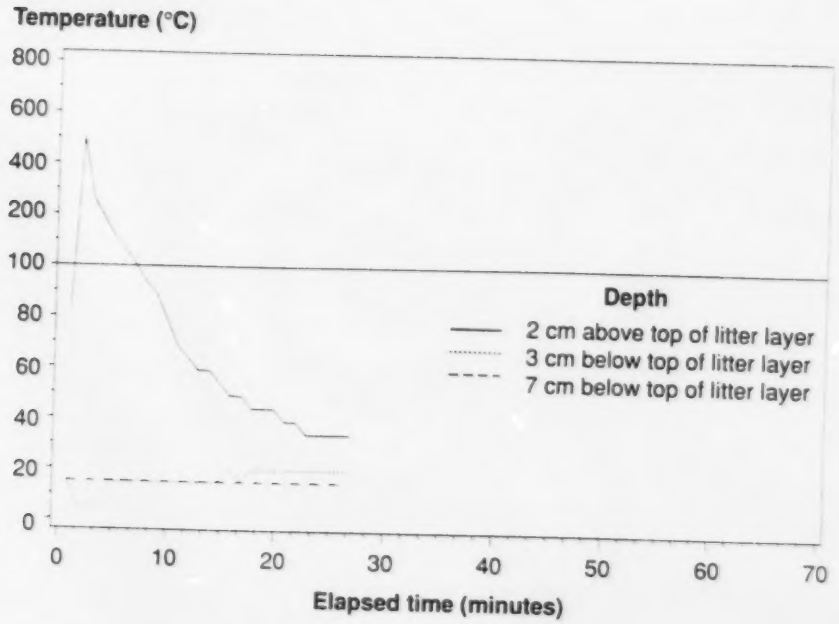

FIGURE 6. Temperature history in a subplot with little forest floor depth reduction (0.5 cm depth of burn).

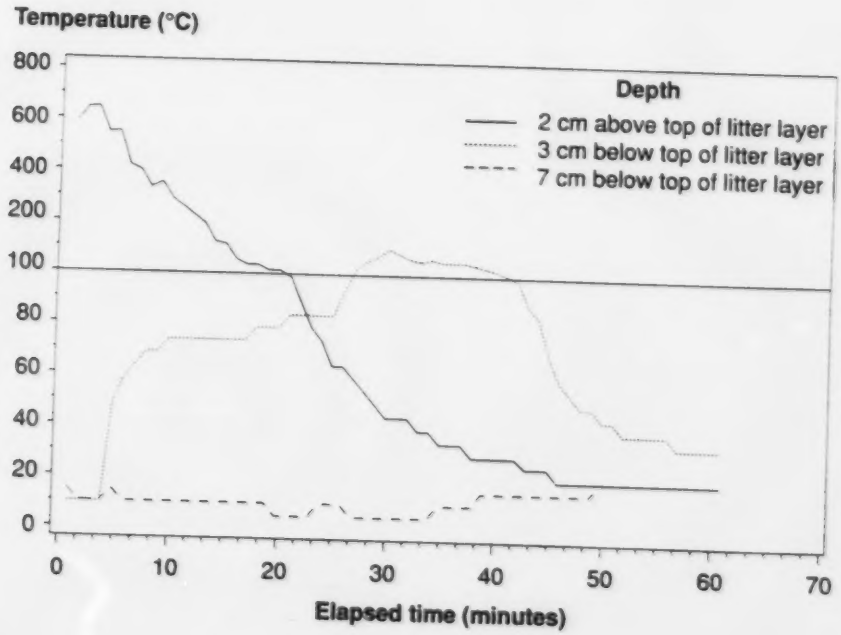

FIGURE 7. Temperature history in a subplot with moderate forest floor depth reduction (4.0 cm depth of burn).

bulldozer traffic between windrows, and to reduction of soil porosity as a result of burning within windrows. Windrowing in this study may have had less effect on bulk density because there was less disturbance, or because the sampling intensity (n = 12) may have been insufficient to detect any change.

Soil Nutrient Status

The forest floor, as well as mineral soil portions of forest soils, is heterogeneous in the undisturbed state (Quesnel and Lavkulich 1980; Carter and Lowe 1986). Superimposing onto this natural variability secondary influences (such as prescribed fire which does not spread or consume fuels uniformly, and mechanical treatments which do not affect soils uniformly), requires that the interpretation of soil nutrient status data be conservative.

Forest floor

Forest floor (L,F,H horizons) nutrient concentrations and contents in the main treatments are compared in Tables 6 and 7. Total N and S concentrations in the forest floor were significantly lower ($p \leq 0.05$) after all treatments. Total P, available K, and extractable NH_4^+ concentrations were also significantly lower after 1 year in the windrow treatment. However, there were significant increases ($p \leq 0.05$) in total and available Ca and total K concentrations in the broadcast burn and the spray & burn treatments, which were probably due to deposition of ash from slash consumption. Available NO_3^- concentrations were also significantly greater ($p \leq 0.05$) in the spray & burn treatment than in the other treatments. This may be due to increased nitrification resulting from warmer temperatures in the spray & burn treatment. Between treatments, available Ca was greater in the broadcast burn and the spray & burn than in the windrow treatments; and total N and extractable NO_3^- were greater in the spray & burn treatment than in the windrow treatment, in the year following treatment.

The reduction in forest floor mass in all the treatments was reflected in significant decreases in total P and S content in all treatments, and in decreases in available K content in the windrow and the broadcast burn treatment. There was probably a decrease in total N content as well, because both N concentrations and forest floor mass were reduced, but this could not be verified statistically. However, increases occurred in available Ca content in the broadcast burn and the spray & burn treatments, in total Ca content in the broadcast burn treatment, and in extractable NO_3^- content in the spray & burn treatment — all of which reflect significant increases ($p \leq 0.05$) in concentrations of these nutrients. Comparing all treatments, total Ca content in the broadcast burn and NO_3^- content in the spray & burn were greater than in the windrow treatment in the year following treatment.

Apparent losses of P and S from the forest floor as a result of burning were lower than estimated losses from the forest floor after broadcast burns in logging slash in the SBS zone (Taylor and Feller 1986; Macadam 1987) and after broadcast site rehabilitation burns in dense lodgepole pine (Blackwell *et al.*[3] This difference is consistent with the lower forest floor consumption in this study. Forest floor nutrient loss estimates from the windrow treatments in this study were also much less than those found by Blackwell *et al.*[4] for between windrow areas, probably because the degree of soil disturbance was much less in this study. However, as was mentioned earlier under "Fuel Consumption," the methods used may have underestimated initial forest floor mass and changes in forest floor nutrient content.

Mineral soil

Nitrogen concentrations and contents in the disc-trenched and non-trenched treatments are compared in Table 8, and in all treatment regimes in Tables 9 and 10. Increases were significant ($p \leq 0.05$) in extractable NH_4^+ concentrations in the mineral soil in all treatments. They were also significant ($p \leq 0.05$) for extractable NO_3^- in the spray & burn, and the spray, burn and disc-trench treatments, possibly because of enhanced nitrification. No significant differences ($p \leq 0.05$) occurred in nutrient concentrations or content, attributable to disc-trenching. However, only the shoulder of the berm at the

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[3] Blackwell *et al.*, 1989.
[4] Ibid.

TABLE 6. Comparison of mean forest floor nutrient concentrations between main site preparation treatments

Treatment	Total N (%)			Total P (%)			Total S (%)			Total K (%)			Total Mg (%)		
	Pre[1]	Post	Change[2]	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Windrow	1.20b	0.79b	-0.41**	0.11a	0.06a	-0.05*	0.12a	0.07a	-0.05**	0.23a	0.29a	0.06	0.20a	0.19a	-0.01
Broadcast burn	1.22b	0.83b	-0.39**	0.10a	0.08a	-0.02	0.12a	0.06a	-0.06**	0.20a	0.30a	0.10**	0.17a	0.21a	0.03
Spray & burn	1.45a	1.00a	-0.45**	0.10a	0.07a	-0.02	0.13a	0.08a	-0.05**	0.20a	0.27a	0.07*	0.19a	0.18a	-0.00

Treatment	Total Ca (%)			Extractable NO_3 (ppm)			Extractable NH_4 (ppm)			Available K (meq/100g)			Available Mg (meq/100g)		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Windrow	1.20a	1.16a	-0.04	2.4a	2.8a	0.4	86.5a	58.0a	-28.5*	2.3a	1.3a	-1.0*	6.5a	4.9a	-1.6
Broadcast burn	1.14a	1.61a	0.47**	2.2a	3.4a	1.1	76.7a	81.6a	4.9	2.2a	1.5a	-0.7	6.1a	6.3a	0.2
Spray & burn	1.43a	1.78a	0.36**	2.8a	22.6b	20.2**	86.7a	73.8a	-12.9	1.8a	1.5a	-0.3	7.1a	6.5a	-0.6

Treatment	Available Ca (meq/100g)		
	Pre	Post	Change
Windrow	34.1a	38.2a	4.1
Broadcast burn	28.8a	57.8b	29.0**
Spray & burn	38.5a	70.3b	31.8**

[1] Pre- and post-treatment means within columns followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; $n = 24$.
[2] * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; $n = 6$ (each observation is the mean of four subsamples).

TABLE 7. Comparison of mean forest floor nutrient contents (kg/ha) between main site preparation treatments

	Total N			Total P			Total S			Total K			Total Mg		
Treatment	Pre[1]	Post	Change[2]	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Windrow	460.9a	293.0a	-167.9	38.4a	22.6a	-15.8*	44.8a	25.6a	-19.2*	82.2a	110.4a	28.2	64.4a	65.8a	1.4
Broadcast burn	521.4a	335.0a	-186.4	43.3a	29.6a	-13.7*	53.4a	26.4a	-27.0*	90.7a	113.8a	23.1	73.4a	74.3a	0.9
Spray & burn	568.5a	321.5a	-247.0	39.2a	24.4a	-14.8*	50.4a	25.5a	-24.9*	72.2a	91.6a	18.9	70.2a	60.3a	-9.8

	Total Ca			Extractable NO_3			Extractable NH_4			Available K			Available Mg		
Treatment	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Windrow	424.4a	423.2a	-1.2	0.1a	0.1a	0.0	3.3a	2.2a	-1.1	31.7a	18.5a	-13.4*	27.0a	22.2a	-4.8
Broadcast burn	498.8a	652.3b	+153.5*	0.1a	0.3a	0.2	4.2a	3.1a	-1.1	35.6a	21.8a	-13.8*	29.6a	29.2a	-0.4
Spray & burn	625.6a	560.6ab	-65.0	0.1a	0.7b	0.6**	3.0a	2.6a	-0.4	25.6a	19.5a	-6.1	32.3a	25.8a	-6.5

	Available Ca		
Treatment	Pre	Post	Change
Windrow	254.0a	282.5a	28.5
Broadcast Burn	256.5a	446.2a	189.7*
Spray & burn	324.0a	436.4a	112.4*

[1] Pre- and post-treament means within columns followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 24.
[2] * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; n = 6 (each observation is the mean of four subsamples).

TABLE 8. Comparison of mean mineral soil nitrogen concentration and content between disc-trenching treatments

		Concentrations[1]		Content (kg/ha)	
		N[2]	D	N	D
Total N	Pre[3]	0.169a	0.131a	1163.4a	980.2a
(%)	Post	0.148a	0.137a	1169.5a	1169.1a
	Change	-0.021	0.002	-80.6	146.8
Extractable	Pre	9.0a	8.7a	7.0a	6.3a
NH_4^+ (ppm)	Post	29.1a	25.6a	22.1a	22.2a
	Change	20.2*	16.8*	15.2*	15.8*
Extractable	Pre	1.20a	1.23a	0.9a	0.9a
NO_3^- (ppm)	Post	4.53a	5.14a	4.6a	6.4a
	Change	3.34*	3.91*	4.0*	6.3*

1 Units given in parentheses.
2 N = non-trenched; D = disc-trenched.
3 For each variable, means within rows followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 24.
4 * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; n = 6 (each observation is the mean of four subsamples).

TABLE 9. Comparison of mineral soil nitrogen concentrations between site preparation regimes

Nutrient		Windrow		Broadcast burn		Spray & burn	
		N[1]	D	N	D	N	D
Total N	Pre	0.190a	0.127a	0.129a	0.140a	0.188a	0.124a
(%)	Post	0.153a	0.163a	0.123a	0.105a	0.168a	0.142a
		-0.037	-0.036	-0.005	-0.035	-0.020	-0.018
Extractable	Pre	9.68a	9.54a	7.12a	7.50a	10.29a	9.09a
NH_4^+ (ppm)	Post	24.58a	26.88a	30.92a	24.92a	31.79a	24.92a
		14.90**	17.33*	23.79**	17.41*	21.5**	15.83*
Extractable	Pre	1.3a	1.2a	1.1a	1.4a	1.2a	1.0a
NO_3^- (ppm)	Post	3.1a	3.6a	1.8a	1.4a	8.7a	10.4a
		1.7	2.4	0.7	-0.04	7.5*	9.3*

1 N = non-trenched; D = disc-trenched.
2 For each variable, means within rows followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 24.
3 * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; n = 6 (each observation is the mean of four subsamples).

TABLE 10. Comparison of mean mineral soil nitrogen content (kg/ha) between site preparation regimes

Nutrient		Windrow		Broadcast burn		Spray & burn	
		N[1]	D	N	D	N	D
Total N	Pre	1159.5a	1087.0a	953.6a	1013.7a	1368.0a	849.4a
	Post	1313.0a	1444.0a	971.4a	957.0a	1028.0a	1107.5a
		153.2	357.4	17.9	-56.6	-339.9	258.0
Extractable	Pre	7.7a	7.7a	5.3a	4.9a	7.8a	6.5a
NH_4^+	Post	21.1a	22.9a	25.8a	23.6a	19.2a	20.1a
		13.4*	15.2*	20.5**	18.7*	11.5*	13.6*
Extractable	Pre	1.0a	1.0a	0.8a	1.0a	0.9a	0.7a
NO_3^-	Post	3.6a	3.8a	2.6a	3.0a	6.6a	11.0a
		2.6	2.9	1.6	2.0	5.7	10.3**

[1] N = non-trenched; D = disc-trenched.
[2] Means within rows followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 24.
[3] and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; n = 6 (each observation is the mean of four subsamples).

same height as the surface of the undisturbed soil was sampled in this study, and a different result may be found if other positions in the trench profile were examined. Greater nutrient concentrations might be found in portions of the berm that incorporated forest floor material; lower nutrient concentrations might be found in the soil on the bottom of the trenches, as concentrations of N, P, and S generally decrease with depth in the mineral soil.

The use of bulk soil sampling to evaluate changes in nutrient status in this study probably did not allow for differentiation of some treatment effects, because of the large spatial variability in nutrient concentrations. More conclusive interpretations about treatment effects on available nutrient forms might be made by the use of lysimetry or ion exchange resins.

Microclimate

Climate during the study period

The background climate, which accounts in part for how site preparation treatments affect microclimate, was monitored during the study period so that it could be compared with estimated normals. Three years of weather data obtained at the study site showed that the monthly average temperature at Stony Lake could be well predicted from Prince George Airport values for the same time period. This relationship was used to predict 30-year temperature "normals" for the study site. Mean monthly temperatures during the growing season are plotted against the normals in Figure 8.

It appears that monthly average temperatures during the first two growing seasons following planting were close to the expected normals. In contradistinction to temperature, precipitation at Stony Lake could not be predicted very well from values at other nearby climate stations. Figure 9 shows accumulated precipitation during the growing season for the 3 years 1987 to 1989. For comparison, the 3-year average is also plotted. In general, precipitation was ample and fairly uniformly distributed through early and mid-season, and relatively light during September.

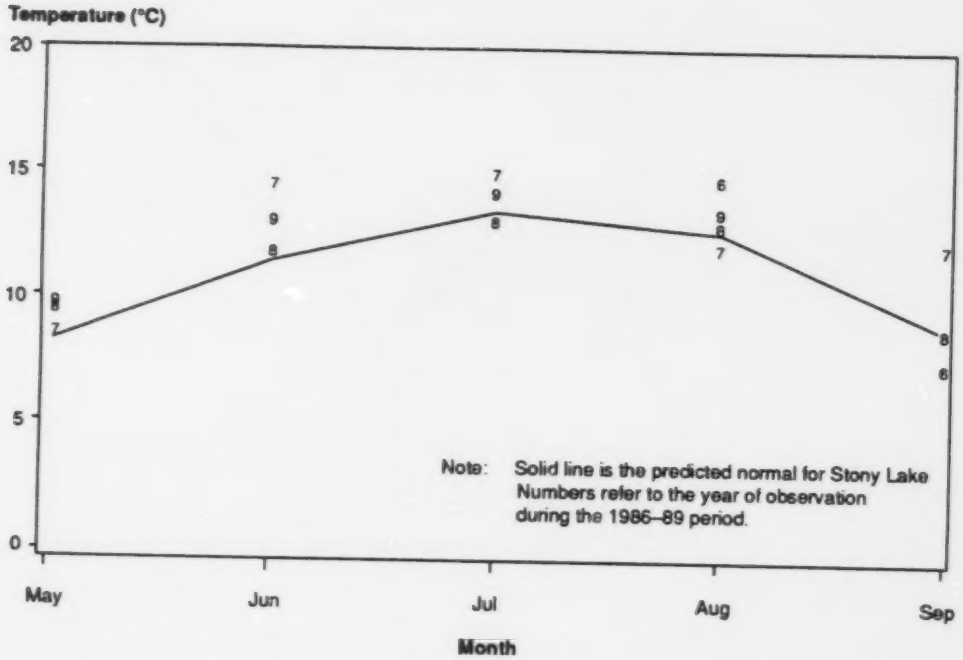

FIGURE 8. Mean monthly air temperature at the study site during the 1986–1989 growing seasons.

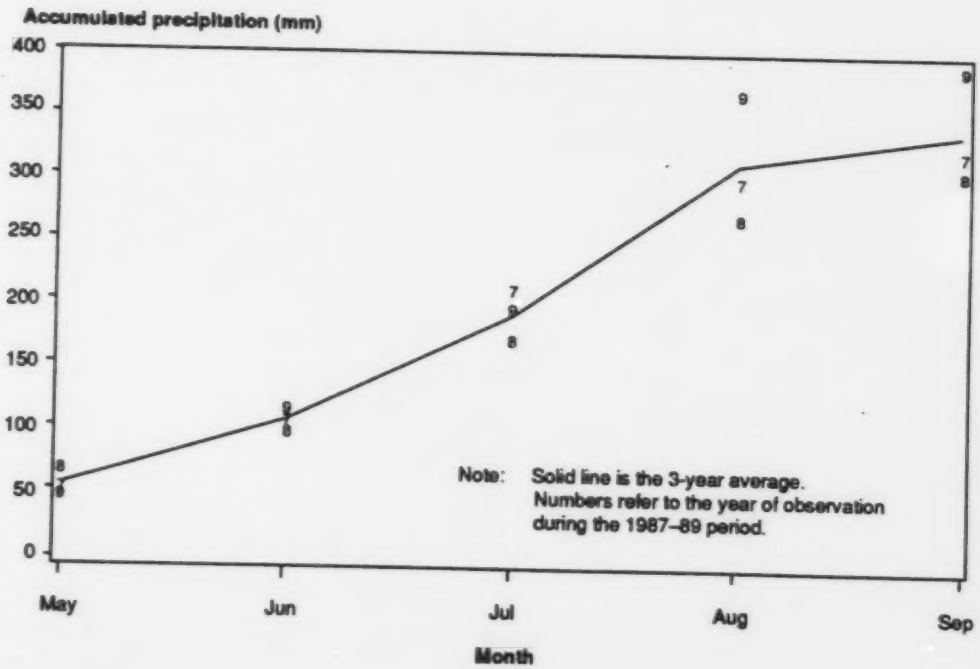

FIGURE 9. Accumulated precipitation at the study site during the 1987–1989 growing seasons (beginning May 1).

Microclimate effects

The analysis of site preparation effects on microclimate is based on data from continuous monitoring and spot sampling. Inferences about diurnal and seasonal patterns came mainly from only one of the three sets of continuously monitored sites, and these have not yet been confirmed by statistical tests. Statistical inferences about treatment effects were based on the spot sampling data only, as the analysis of the continuous sampling data was not complete at the time this report was written. These inferences should be interpreted with care, because the spot sampling was only carried out during the pre-dawn hours on a few occasions during each growing season, and results might be different at different times of the day, or following various weather sequences at different times of the season.

Figure 10 shows the pattern of daily average soil temperatures at the 10 cm depth during the 1989 growing season for one block of windrow, windrow and disc-trench, spray & burn, and spray & burn and disc-trench plots. Higher temperatures from disc-trenching are evident. Compared with the windrow trenched plot, the spray & burn trenched plot tended to be warmer in the early part of the season, similar in mid-season, and cooler in late season. The periods of pronounced cooling in the windrow trenched plot at the end of April and again at the end of July are not readily explained, but may be due to greater vegetation cover.

Table 11 gives pre-dawn soil temperatures at the 10 cm depth in the windrow, windrow and disc-trench, and spray & burn regimes, obtained by spot sampling at selected dates during the first two growing seasons following treatment. There were no significant differences ($p \leq 0.05$) in pre-dawn temperature between the windrow and the spray & burn regimes. Pre-dawn temperatures in the windrow and disc-trench regime were significantly greater ($p \leq 0.05$) than in the windrow and the spray & burn regimes during the middle of the growing season, but differences at either end of the growing season were not consistent.

Figures 11 and 12 illustrate the diurnal pattern of soil temperature at the 10 cm depth at two times during the first year following treatment (before and after vegetation regrowth) for the same set of plots represented in Figure 10. These diagrams are remarkable because vegetation regrowth does not appear to have reduced the amplitude of the diurnal variation; in fact, amplitude seemed to increase. Phase relationships are also somewhat surprising. As expected, the spray & burn trenched site warmed up and cooled more rapidly than the spray & burn site because of the greater amount of mineral soil exposure. The windrow site lagged behind the burned site, but this could be explained by lower forest floor depths in the burned site. However, the windrow and disc-trenched site shows the greatest lag and a relatively small diurnal amplitude. No satisfactory explanation has been found for this observation.

Figures 11 and 12 also suggest that treatment differences may be more pronounced than is suggested by the pre-dawn spot sampling data. For example, the curve for the windrow treatment is distinctly different from that of the spray & burn treatment, whereas the statistical analysis of the spot measurements found no significant difference between these two treatments. This apparent contradiction highlights both the necessity for replication and the necessity for precision in specifying measures of temperature. For this study, the inter-site variability was such that no significant treatment differences between spot measurements of pre-dawn temperatures were found. However, Figures 11 and 12 suggest that differences might have been found if spot measurements had been carried out in the afternoon.

Figure 13 shows an example of the trend in soil moisture at the 10 cm depth for a windrow site and a spray & burned trenched site, based on the continuous data set during the 1988 growing season. Generally, soil moisture was more than ample in both treatments, and the seedlings and vegetation were seldom under significant water stress, except for short periods on the spray & burn trenched site. The tendency, during warm dry weather, for berm soil in the disc-trenching treatments to dry out more quickly and to a greater degree than soils with intact forest floor is evident.

Pre-dawn soil moisture potential measurements determined by spot sampling are given in Table 12. Although the analysis suggests that there were some statistical differences between treatments, conditions were so moist that the differences would not likely have been significant to plant response. There were no significant differences ($p \leq 0.05$) in the pre-dawn water potential of spruce seedlings in the

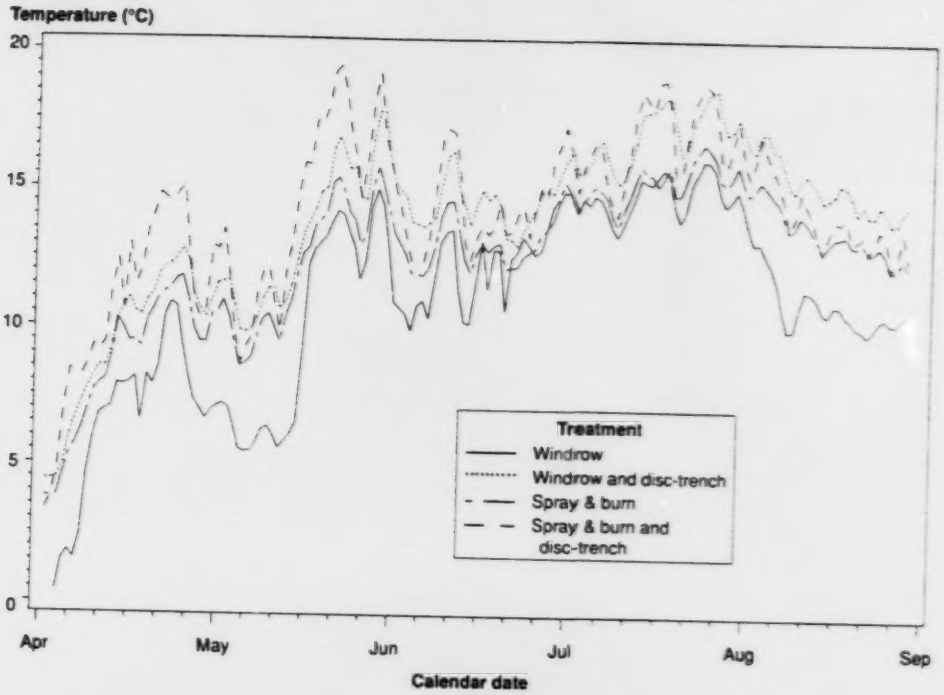

FIGURE 10. Season trend in daily average soil temperature (10 cm depth) by treatment during the 1989 growing season. Data are from one site per treatment only.

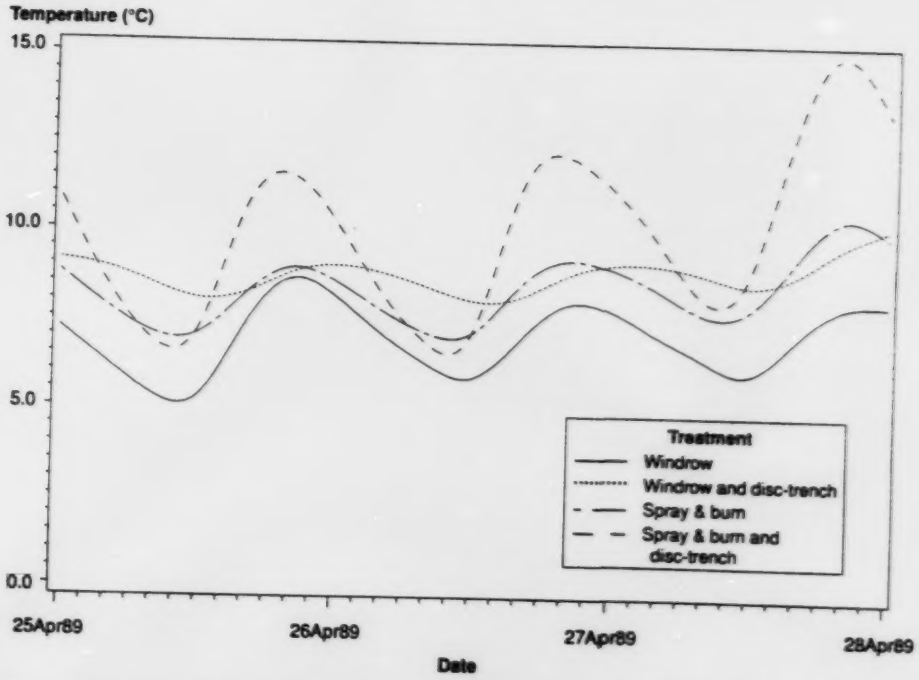

FIGURE 11. Diurnal trend in soil temperature (10 cm depth) before vegetation regrowth in 1989. Data are from one site per treatment only.

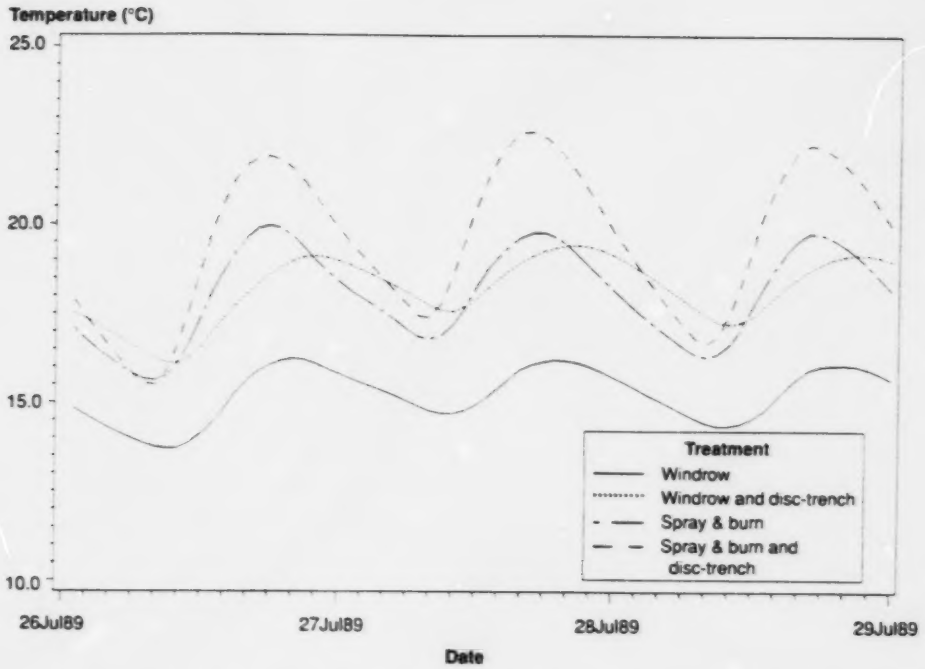

FIGURE 12. Diurnal trend in soil temperature (10 cm depth) after vegetation regrowth in 1989. Data are from one site per treatment only.

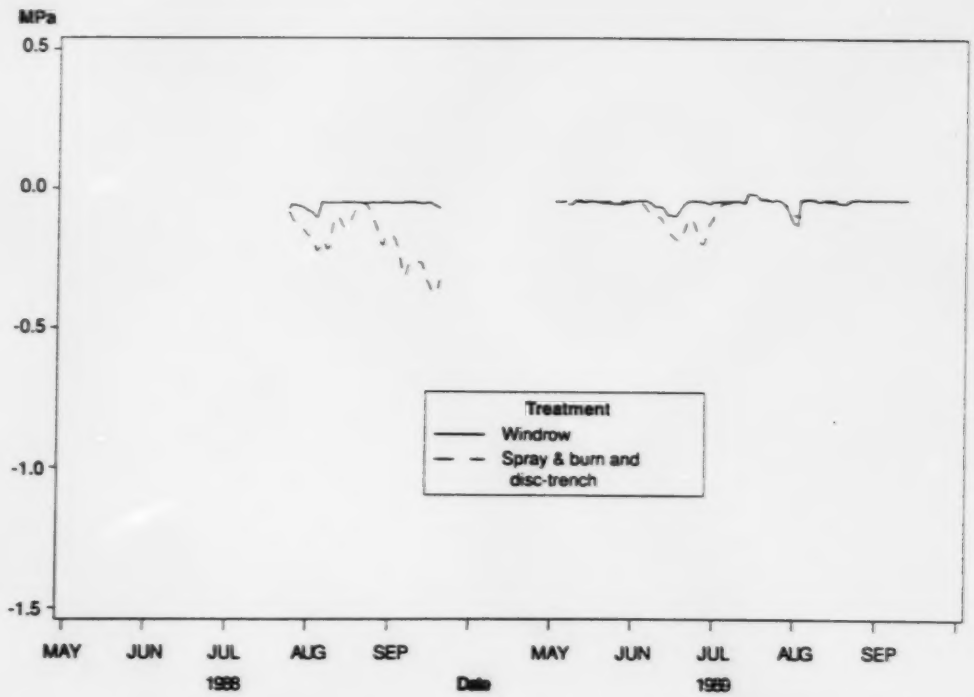

FIGURE 13. Season trend in daily average soil moisture (10 cm depth) by treatment during the 1988 and 1989 growing seasons. Data are from one site per treatment only.

TABLE 11. Spot sample pre-dawn soil temperatures at 10 cm during the first two growing seasons (1988, 1989)

Sample date	n[1]	Windrow		Spray & burn (non-trenched)	
		Non-trenched	Disc-trenched		
June 26, 1988	9	12.1a[2]	13.1b	12.1a	(6)
July 20, 1988	9	12.8a	14.8b	13.0a	(6)
September 17, 1988	9	9.5a	8.3b	8.9ab	(6)
1988	27	11.4a	12.1a	11.4a	(18)
June 2, 1989	9	11.0a	11.1a	10.0a	(6)
July 14, 1989	9	12.9a	14.4b	12.5a	(6)
1989	18	11.9ab	12.8a	11.2a	(12)
1988–1989	45	11.6ab	12.3a	11.3a	(30)

[1] Sample number except where given in parentheses.
[2] LSD method; values within rows followed by the same letter are not significantly different at $p < 0.05$.

TABLE 12. Pre-dawn soil moisture potentials (MPa)[1] at 10 cm depth at selected periods during the first two growing seasons (1988,1989)

Sample date	Windrow		Spray & burn	
	Non-trenched	Disc-trenched	Non-trenched	Disc-trenched
June 26, 1988	0.025b[2]	0.027b	0.015a	0.011a
July 20, 1988	0.029bc	0.032c	0.013a	0.015ab
September 17, 1988	0.021a	0.028a	0.023a	0.042b
1988	0.024b	0.028b	0.016a	0.024b
June 2, 1989	0.014a	0.024b	0.013a	—
July 14, 1989	0.012a	0.017b	0.014ab	0.023c
September 14, 1989	0.012a	0.026b	0.013a	0.038c
1989	0.012a	0.019b	0.014a	0.026c
1988–1989	0.017a	0.023b	0.015a	0.023b

[1] Values shown are negative.
[2] LSD method; values within rows followed by the same letter are not significantly different at $p < 0.05$; n = 12, 12, 12, and 3 for the individual sample dates for the windrow, windrow and trenched, spray & burn, and spray & burn and trenched treatment regimes, respectively.

corresponding treatments. Consequently, measurements on spruce seedlings were pooled and then compared against other vegetation (Table 13). The moisture potential of spruce was significantly lower ($p \leq 0.05$) than fireweed (greater stress) only on the June sampling date in the second growing season; and, except for late in the season, twinberry shows lower water potentials than both fireweed and spruce.

Tables 12 and 13 suggest that pre-dawn plant water potentials are conspicuously lower than soil moisture potentials. However, the soil was generally wet and absolute differences were not great. Table 12 indicates that soil moisture never dropped below field capacity, but the portion of the continuous data set shown in Figure 13 suggests that the spray & burn trenched sites may be subject to periods of soil moisture less than -0.2 MPa, and that the spot sampling technique may not have captured these drier periods.

TABLE 13. Comparison of mean pre-dawn water potentials (MPa)[1] of spruce seedlings and competing vegetation at selected periods during the first two growing seasons (1988, 1989)

Sample date	Spruce	Fireweed	Twinberry	Thimbleberry
June 26, 1988	0.24a[2]	0.19a	0.69b	—
July 20, 1988	0.42a	0.62b	0.80c	—
September 17, 1988	0.44a	0.19a	0.36a	—
1988	0.34a	0.30a	0.63b	—
June 2, 1989	0.28b	0.16c	0.47a	—
July 14, 1989	0.11a	0.11a	—	0.12a

[1] Values shown are negative.
[2] LSD method; values within rows followed by the same letter are not significantly different at $p < 0.05$; n = 9, 3, and 3 for spruce, fireweed, and thimbleberry means on the individual sample dates, respectively.

Vegetation Development

Vegetation cover and volume means in the main site preparation treatments are compared in Table 14. The spray & burn treatment had the most pronounced effect on vegetation in the first two growing seasons. In the spray & burn there was significantly lower ($p \leq 0.05$) volume of thimbleberry (*Rubus parviflorus* Nutt.) and of total vegetation in the first year, and lower cover and volume of twinberry and fireweed in the first two years, compared to in the burn and the windrow treatments. However, raspberry (*Rubus idaeus* L.) cover and volume, and the volume of grasses (primarily *Calamagrostis canadensis* (Michx.) Beauv.) were greater in the spray & burn treatment compared to in the burn and the windrow treatments, and the burn treatment, respectively, in the second year.

Vegetation cover and volume means in the disc-trenched and non-trenched treatments are compared in Table 15. There was significantly lower ($p \leq 0.05$) thimbleberry cover and volume in the first year, and grass and total cover in the second year in the disc-trenched treatments. Raspberry cover and volume were significantly greater ($p \leq 0.05$), however, in the disc-trenched treatments in the second year. The means of the six site preparation regimes are compared in Table 16.

Figures 14–16 illustrate trends in species volume within the windrow, burn, and spray & burn regimes over the three pre- and post-treatment sampling times. Pre-treatment vegetation values in the windrow treatment were estimated from the mean pre-burn values. In the first year, total vegetation volume was less than pre-treatment values in all treatments, but it recovered to near pre-treatment values in the windrow and the burn treatments in the second growing season. Twinberry volume in the first 2 years was lower than before treatment in all treatments. By the second growing season, fireweed volume was greater than pre-treatment volumes in the windrow and the burn treatments, but had not recovered to pre-treatment levels in the spray & burn treatment.

Thimbleberry, grass, and raspberry volume exceeded pre-treatment values in all treatments by the second growing season. The rapid regeneration of thimbleberry following spraying may have occurred because, at the time of spraying, fireweed and twinberry over-topped the thimbleberry and probably received more herbicide. Furthermore, early growing season applications of glyphosate, as in this study, may have less effect on thimbleberry than on other species. Figures 14–16 also suggest that, although the volume of one or more species may be reduced by particular treatments, this may result in an increase in the volume of other species.

Several other woody shrubs that may compete with conifer seedlings, or that are favoured as browse by moose, also occurred on the study site. These include trembling aspen (*Populus tremuloides* Michx.), sitka alder (*Alnus sinuata* Regel), paper birch (*Betula papyrifera* Marsh.), rose (*Rosa acicularis* Lindley), currant (*Ribes lacustre* (Pers.) Poir. in Lam.), black huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.), red osier dogwood (*Cornus sericea* L.), and willows (*Salix* spp.). Aspen resprouted vigorously from cut stumps

TABLE 14. Comparison of mean vegetation cover and volume between main site preparation treatments in the first two growing seasons

		Twinberry	Raspberry	Thimbleberry	Fireweed	Grass	Total
Cover (%)							
1988	Windrow	2.8a	0.7a	12.0a	16.0a	2.2a	41.2a
	Broadcast burn	2.0a	0.5a	8.8a	19.5a	1.2a	41.5a
	Spray & burn	0.0b	1.3a	7.9a	7.9b	1.7a	29.5a
1989	Windrow	5.0a	1.6b	16.8a	20.3a	5.7a	64.9a
	Broadcast burn	3.5a	0.7b	13.5a	19.4a	6.5a	58.9a
	Spray & burn	0.2b	10.4a	15.5a	10.0b	8.2a	62.2a
Volume (m^3/m^2)							
1988	Windrow	0.016a	0.002a	0.035a	0.099a	0.013a	0.188a
	Broadcast burn	0.011a	0.002a	0.024ab	0.129a	0.005a	0.196a
	Spray & burn	0.000a	0.002a	0.019b	0.031b	0.007a	0.085b
1989	Windrow	0.033a	0.005b	0.054a	0.128a	0.038ab	0.306a
	Broadcast burn	0.024a	0.002b	0.038a	0.123a	0.024b	0.252a
	Spray & burn	0.001b	0.035a	0.047a	0.054a	0.055a	0.232a

[1] For each species in each year, means followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 120.

TABLE 15. Comparisons of mean vegetation cover and volume between disc-trenching treatments in the first two growing seasons

		Twinberry	Raspberry	Thimbleberry	Fireweed	Grass	Total
Cover (%)							
1988	Non-trenched	2.0a	0.8a	11.0a	13.6a	2.3a	40.8a
	Disc-trenched	1.3a	0.8a	8.1b	15.3a	1.1a	33.9a
1989	Non-trenched	3.2a	3.9b	14.5a	16.1a	9.1a	66.6a
	Disc-trenched	2.6a	4.6a	16.0a	17.0a	4.5b	58.0b
Volume (m^3/m^2)							
1988	Non-trenched	0.011a	0.002a	0.031a	0.079a	0.012a	0.165a
	Disc-trenched	0.007a	0.002a	0.022b	0.093a	0.005a	0.148a
1989	Non-trenched	0.022a	0.012b	0.046a	0.099a	0.048a	0.276a
	Disc-trenched	0.017a	0.017a	0.047a	0.105a	0.032a	0.250a

[1] For each species in each year, means followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 180.

TABLE 16. Comparison of mean vegetation cover and volume in the first two growing seasons between treatment regimes

Species	Year	Windrow		Broadcast burn		Spray & burn	
		N[1]	D	N	D	N	D
Cover (%)							
Twinberry	1988	4.2a[2]	1.5ab	1.7ab	2.3a	0.0b	0.0b
	1989	6.5a	3.4ab	2.8ab	4.2ab	0.2b	0.2b
Raspberry	1988	0.6a	0.7a	0.4a	0.6a	1.4a	1.2a
	1989	1.5c	1.6c	0.5c	0.9c	10.0b	11.1a
Thimbleberry	1988	11.9a	12.1a	11.5a	6.0b	9.5ab	6.2b
	1989	14.6ab	19.0a	13.8b	11.5b	15.1ab	15.9ab
Fireweed	1988	12.3a	19.7a	20.9a	18.1a	7.7a	8.0a
	1989	17.1ab	23.6a	21.0a	17.9ab	10.3b	9.6b
Grass species	1988	3.1a	1.2a	1.3a	1.0a	2.3a	1.2a
	1989	7.4a	4.3a	9.1a	3.9a	11.1a	5.5a
Total	1988	42.0a	40.4a	47.5a	35.5a	33.1a	25.9a
	1989	67.4a	62.4a	65.4a	52.3a	67.0a	57.4a
Volume (m^3/m^2)							
Twinberry	1988	0.026a	0.007ab	0.008ab	0.015a	0.000b	0.000b
	1989	0.048a	0.018ab	0.017ab	0.031ab	0.001b	0.001b
Raspberry	1988	0.002a	0.003a	0.001a	0.002a	0.003a	0.002a
	1989	0.005c	0.005c	0.002c	0.003c	0.028b	0.042a
Thimbleberry	1988	0.035a	0.036a	0.034a	0.015b	0.024ab	0.015b
	1989	0.060ab	0.059a	0.040b	0.036b	0.048ab	0.046ab
Fireweed	1988	0.073a	0.124a	0.137a	0.121a	0.027a	0.035a
	1989	0.105ab	0.152a	0.138a	0.108ab	0.054b	0.055b
Grass species	1988	0.019a	0.006a	0.005a	0.004a	0.010a	0.005a
	1989	0.050ab	0.029ab	0.023b	0.024ab	0.070a	0.041ab
Total	1988	0.187a	0.189a	0.213a	0.178a	0.094a	0.076a
	1989	0.323a	0.289a	0.265a	0.224a	0.241a	0.222a

[1] N = non-trenched, D = disc-trenched.

[2] For each variable, means within rows followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 60. Means of 0.000 are less than 0.0005.

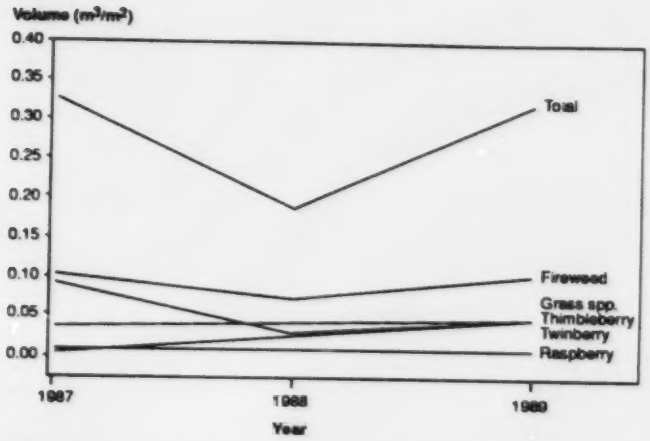

FIGURE 14. Trend in mean vegetation volume in the first two growing seasons following windrowing (1987 values are pre-treatment averages for the burn and the spray & burn treatments; n = 30).

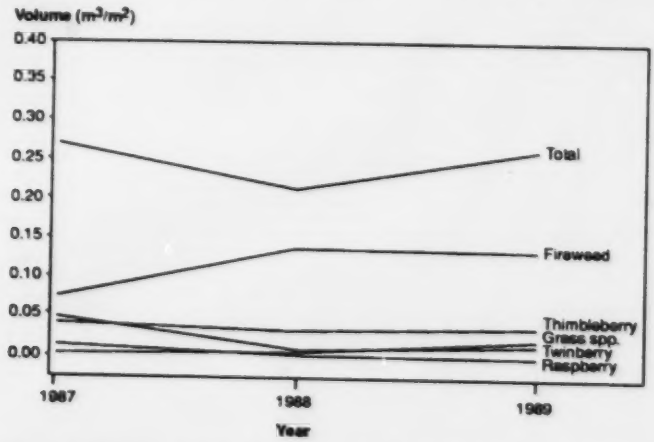

FIGURE 15. Trend in mean vegetation volume in the first two growing seasons following broadcast burning (1987 values are pre-treatment; n = 30).

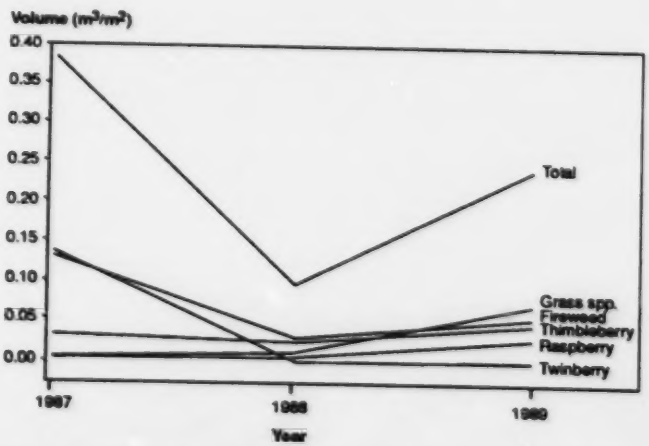

FIGURE 16. Trend in mean vegetation volume in the first two growing seasons following spraying & burning (1987 vlaues are pre-treatment; n = 30).

and from roots, increasing above pre-treatment levels in areas where stems occurred in the residual stand. The volumes of all the other species were lower than pre-treatment values in the first two growing seasons in all the treatments, but some regeneration of all species occurred in all treatments. However, differences in regeneration of these species between treatments could not be distinguished statistically because of their low initial frequency.

Fire Impact and vegetation response

Correlation analysis was used to examine relationships between vegetation volume in the first two seasons after treatment, and pre-treatment volume, forest floor depth of burn, and forest floor depth remaining in the burn and the spray & burn regimes. Second-year correlation coefficients are given in Table 17. Similar analyses were not carried out for the windrow and the disc-trench treatments, because pre-treatment vegetation assessments were not carried out at permanent sample points in these treatments. In both the first and second year in the burn treatment there were strong positive correlations between fireweed, grass, thimbleberry, twinberry, and total vegetation volume, and pre-treatment vegetation volume. In the spray & burn treatment, there were fewer weaker correlations for thimbleberry, raspberry, and grass. There was a weak negative correlation in the second year between thimbleberry volume and depth of burn in the burn treatment; and between twinberry and total vegetation volume and depth of burn in the spray & burn regime. No significant correlations occurred for these in the first growing season. There were also significant positive correlations between vegetation volume in the spray & burn regime and the depth of forest floor remaining after burning. These correlations suggest that initial vegetation volume had a stronger influence than did forest floor consumption on vegetation response to burning, though forest floor consumption was moderate in this study.

Seedling Establishment

Survival and health

The survival of planted seedlings in the first two growing seasons was uniformly high (greater than 98%) for lodgepole pine and interior spruce in all treatments. About 22% of the spruce seedlings were infected with spruce gall aphid (*Adelges cooleyi*) by the end of the second growing season, but there was no significant difference ($p \leq 0.05$) in the incidence of infection between treatments. The symptoms of infection were variable, with some seedlings showing only slight swelling at the tips of lateral branches, while others had pronounced leader deformities. Lodgepole pine in the PSPs were protected from damage by snowshoe hare browsing with plastic mesh, as mentioned in "Methods." However, browsing of unprotected seedlings outside the plots was observed and appeared to be greater in the windrow and the burn treatments than in the spray & burn treatment. There was a very low incidence of browsing on the unprotected spruce.

TABLE 17. Correlation coefficients (r) of second growing season vegetation volume with pre-treatment and vegetation volume, forest floor depth of burn, and remaining forest floor depth in the burn treatments

	Fireweed	Grass	Thimbleberry	Twinberry	Raspberry	Total
			Broadcast burn			
Initial spp. vol.	0.60**[a]	0.42**	0.66**	0.39**	0.83**	0.49**
Depth of burn	NS	NS	-0.36*	NS	NS	NS
Depth remaining	NS	NS	NS	NS	NS	NS
			Spray & burn			
Initial spp. vol.	NS	0.30*	0.54**	NS	0.29*	NS
Depth of burn	NS	NS	NS	-0.38	NS	-0.38*
Depth remaining	0.38*	0.41**	0.47**	0.41**	0.38*	0.56**

[a] Correlation coefficients followed by * or ** are significant at $p < 0.05$ and $p < 0.01$, respectively; $n = 30$.

Growth and form

There were noteworthy differences in the size, increment, and form of planted seedlings between tree species and between site preparation treatments in the first two growing seasons. Mean growth measures for the pine and spruce seedlings are compared in Table 18, and the main site preparation treatments are compared in Table 19. The spruce stock was larger than the pine at the time of planting, but was similar to or exceeded by pine in size and mass by the end of the second growing season. The spray & burn treatment had the most pronounced effect on seedling growth, which was probably due mainly to the lower cover and volume of competing plant species in this treatment. Seedling diameter, volume index, and total mass were significantly greater in the spray & burn than in the burn and the windrow treatments in the first two growing seasons. Seedling diameter and height increment, total height, and needle and root mass were also significantly greater in the spray & burn treatment than in the other treatments in the second growing season. In the first growing season, total seedling mass was also significantly greater in the burn treatment than in the windrow treatment. However there was no difference between the burn and windrow treatments in the second growing season.

Mean growth measures in the disc-trenched and non-trenched treatments are compared in Table 19. Seedling diameter, and needle and root mass were significantly greater, and height/diameter ratio significantly lower (stockier form) in the disc-trenched than in the non-trenched treatments in both the first and second growing seasons. The greater root mass may be due to warmer soil temperatures, and also to somewhat greater moisture stress in the berm soils at some periods of the year. The lower height/diameter ratio may reflect lower vegetation competition levels in the disc-trenched treatments.

Individual treatment regime means are given in Table 20 and trends in volume index of the spruce and pine in these regimes are shown in Figures 17 and 18, respectively. Two years after planting, seedling volume was greatest for lodgepole pine in the spray & burn trenched regime and least for spruce in the windrow regime. Figure 17 also suggests that for lodgepole pine, seedling response to disc-trenching was greater where it followed the spray & burn and the burn treatments rather than the windrow treatment. This may be due in part to a positive interaction between disc-trenching and the suppression of competing vegetation on seedling growth.

Foliar nutrient concentrations

The mean foliar macro-nutrient concentrations in the current year's needles of the pine and spruce seedlings in the first two growing seasons are compared in Table 22. Spruce had significantly greater P, K, and Ca values in both growing seasons; pine had greater N and S values in the first growing season.

Mean foliar nutrient concentrations in the main treatments, the disc-trenching treatments, and all regimes are compared in Tables 23, 24, and 25, respectively. Nitrogen and S concentrations were significantly greater in the spray & burn than in the burn and the windrow treatments in the first growing season; K concentrations were greater in the burn than in the windrow treatment in the second growing season. Nitrogen and K concentrations were also significantly greater in the disc-trenched than in the non-trenched treatments in the second growing season. The higher foliar nutrient concentrations in these treatments coincided with greater biomass increment, and therefore reflect increased nutrient uptake. Comparing adjacent burned and unburned sites 5 years after planting, Ballard and Hawkes (1989) reported lower N, Cu, and Fe concentrations but greater height growth for spruce on the burned site. This suggests that further monitoring of treatment effects on micro-nutrient concentrations is especially warranted.

TABLE 18. Comparison of mean seedling performance measures between tree species in the first two growing seasons[1]

		Height (cm)	Diameter (mm)	Volume index	Height/ diameter	Height incr. (cm)	Diam. incr. (mm)	Total mass (g)	Root mass (g)	Foliage incr. (g)	Shoot/ root
1988	Lodgepole pine	27.7b	4.4b	1.4b	6.5b	10.8b	—	9.2a	1.7b	2.4a	2.7a
	Interior spruce	34.7a	5.0a	2.4a	7.1a	11.6a	—	6.2b	2.8a	2.2a	2.5a
1989	Lodgepole pine	44.9a	8.2a	8.9a	5.6a	17.7a	3.9a	28.8a	5.0a	10.2a	4.6a
	Interior spruce	42.8b	7.8a	7.5a	5.7a	8.6b	2.8b	23.1b	5.2a	5.2b	3.8b

[1] In each year, means within columns followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 1980 and 54 for size and biomass variables, respectively.

TABLE 19. Comparison of mean seedling performance measures by main site preparation treatment in the first two growing seasons[1]

		Height (cm)	Diameter (mm)	Volume index	Height/ diameter	Height incr. (cm)	Diam. incr. (mm)	Total mass (g)	Root mass (g)	Foliage incr. (g)	Shoot/ root
1988	Windrow	31.4a	4.5b	1.7b	7.1a	11.6a	—	6.8c	2.0a	1.9b	2.6a
	Broadcast burn	31.1a	4.5b	1.8b	6.9a	11.1a	—	7.7b	2.3a	2.2b	2.5a
	Spray & burn	31.1a	5.0a	2.1a	6.3b	10.8a	—	8.7a	2.5a	2.8a	2.6a
1989	Windrow	42.1b	7.5b	6.6b	5.8a	11.1b	3.0b	21.5b	4.4b	5.6b	4.1a
	Broadcast burn	42.6b	7.4b	6.8b	5.9a	12.1b	2.9b	19.2b	3.9b	5.8b	4.0a
	Spray & burn	46.8a	9.1a	11.1a	5.3a	16.3a	4.1a	37.0a	7.0a	11.6a	4.6a

[1] In each year, means within columns followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 1320 and 36 for the size and biomass variables, respectively.

TABLE 20. Comparison of seedling performance measures between disc-trenching treatments in the first two growing seasons[1]

		Height (cm)	Diameter (mm)	Volume index	Height/ diameter	Height incr. (cm)	Diam. incr. (mm)	Total mass (g)	Root mass (g)	Foliage incr. (g)	Shoot/ root
1988	Non-trenched	31.4a	4.6a	1.8a	6.9a	11.2a	—	7.2b	2.0b	2.1b	2.7a
	Disc-trenched	30.9a	4.7a	1.9a	6.6b	11.2a	—	8.2a	2.5a	2.4a	2.4b
1989	Non-trenched	43.8a	7.6a	7.4a	5.9a	12.8a	3.0a	21.6b	3.8b	6.4b	4.7a
	Disc-trenched	43.9a	8.4a	9.0a	5.4b	13.5a	3.6a	30.2a	6.4a	9.0a	3.6b

[1] In each year, means within columns followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 1980 and 54 for the size and biomass variables, respectively.

TABLE 21. Comparison of mean seedling performance measures by species and treatment regime in the first two growing seasons following planting

		Lodgepole pine						Interior spruce					
		Windrow		Broadcast burn		Spray & burn		Windrow		Broadcast burn		Spray & burn	
	Year	N[1]	D	N	D	N	D	N	D	N	D	N	D
Height (cm)	1988	28.8b[2]	27.9b	27.9b	27.2b	27.5b	27.0b	34.6a	34.3a	34.7a	34.6a	35.2a	34.6a
	1989	43.0bc	42.4bc	42.6bc	44.6bc	47.0ab	49.8a	41.6bc	41.5bc	42.6c	40.4c	45.8abc	44.9bc
Diameter (mm)	1988	4.1d	4.4cd	4.1d	4.3cd	4.6bcd	4.7abcd	4.7abcd	4.8abcd	4.9abcd	4.9abc	5.2ab	5.4a
	1989	7.7b	7.7b	7.0b	8.5ab	8.5ab	10.0a	7.0b	7.5b	7.0b	7.2b	8.7ab	9.2ab
Volume index	1988	1.3c	1.4c	1.2c	1.3c	1.6bc	1.6bc	2.1ab	2.1ab	2.3a	2.3a	2.6a	2.7a
	1989	7.1b	7.1b	5.8b	9.4ab	9.8ab	14.2a	5.7b	6.7b	5.8b	6.1b	9.8ab	10.7ab
Height/ Diameter	1988	71.41	64.7abc	68.9ab	64.3abc	60.6bc	58.2c	75.1a	72.0a	72.3a	70.5ab	68.6ab	65.3abc
	1989	57.1ab	56.5ab	61.6a	54.1ab	56.5ab	51.2b	61.3a	56.5ab	62.8a	57.2ab	54.3ab	49.9b
Height incr. (cm)	1988	11.6ab	11.1ab	11.0ab	10.5ab	10.4ab	10.2b	11.5ab	12.3a	11.5ab	11.5ab	11.4ab	11.3ab
	1989	14.5cd	14.7cd	15.4cd	17.8bc	20.5ab	23.0a	7.3e	7.8e	8.0e	6.9e	11.0de	10.7de
Diam. incr. (mm)	1989	3.6abc	3.3bc	2.9bc	4.2ab	3.9abc	5.3a	2.3bc	2.7bc	2.1c	2.3bc	3.5abc	3.8abc
Total mass (g)	1988	5.3a	5.2a	5.1a	6.8a	6.9a	8.0a	7.5a	9.0a	8.8a	10.2a	9.7a	10.2a
	1989	22.5b	20.1b	17.4b	26.7b	33.0b	53.3a	16.4b	27.3b	14.9b	18.0b	25.8b	36.3b
Root mass (g)	1988	1.5ab	1.4b	1.4b	2.0ab	1.8ab	2.1ab	2.2ab	2.8ab	2.5ab	3.3a	2.8ab	3.3a
	1989	3.6b	3.9b	3.0b	5.0b	5.3b	9.5a	3.6b	6.7ab	3.2b	4.6b	4.4b	9.0a
Foliage incr. (g)	1988	1.9ab	1.9ab	1.8b	2.5ab	2.8ab	3.5a	1.7b	2.1ab	2.3ab	2.3ab	2.3ab	2.4ab
	1989	7.4b	6.6b	6.5b	9.7b	11.2b	19.8a	3.2b	5.3b	3.2b	3.8b	6.6b	8.9b
Shoot/ root	1988	2.6a	2.7a	2.8a	2.3a	2.9a	2.8a	2.7a	2.2a	2.6a	2.3a	2.8a	2.1a
	1989	5.1a	4.2a	4.6a	4.4a	5.3a	4.5a	3.8a	3.3a	4.1a	3.1a	5.6a	3.2a

[1] N = non-trenched, D = disc-trenched.

[2] For each variable, means within rows followed by the same letter do not differ significantly at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 330 and n = 9 for the size and biomass variables, respectively.

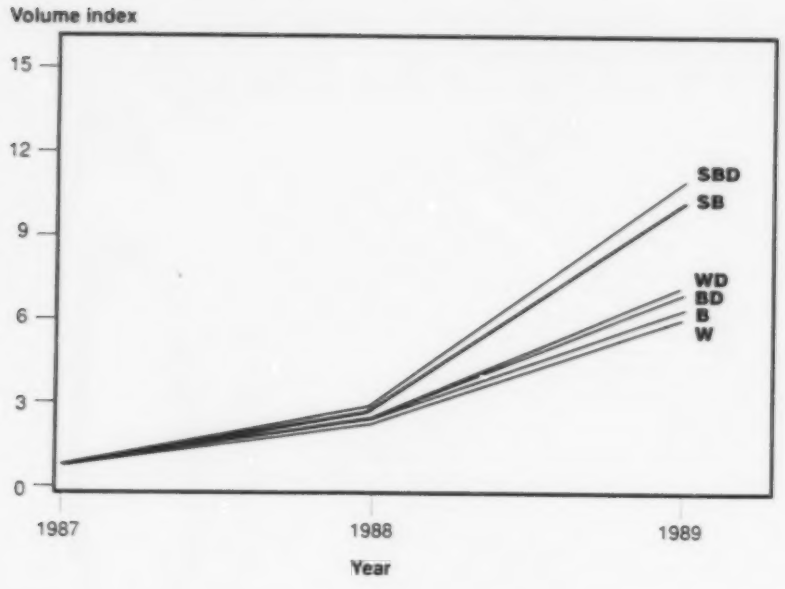

FIGURE 17. Trend in interior spruce volume index in the first two growing seasons following planting (1988, 1989). SB = spray & burn, B = broadcast burn, W = windrow, D = disc-trench.

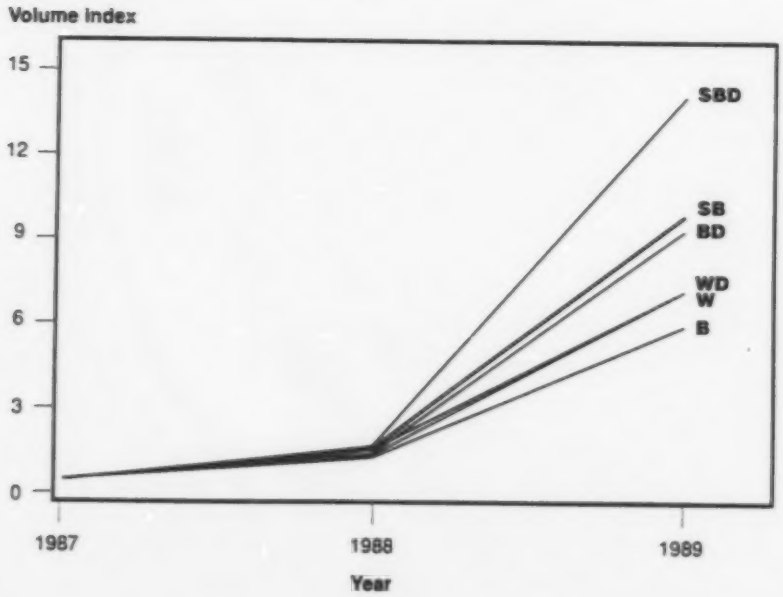

FIGURE 18. Trend in lodgepole pine volume index in the first two growing seasons following planting (1988, 1989). SB = spray & burn, B = broadcast burn, W = windrow, D = disc-trench.

TABLE 22. Comparison of foliar nutrient concentrations between species before planting (pre) and at the end of the first two growing seasons (1988, 1989)

Sampling time	Species	Nutrient concentrations (%)					
		N	P	S	K	Ca	Mg
Pre	Lodgepole pine	2.16	0.39	0.25	1.10	0.40	0.32
	Interior spruce	2.51	0.42	0.28	1.12	0.56	0.21
1988	Lodgepole pine	1.69a[1]	0.22b	0.22a	0.76b	0.24b	0.12a
	Interior spruce	1.41b	0.26a	0.17b	0.84a	0.38a	0.13a
1989	Lodgepole pine	1.52a	0.15b	0.19a	0.64b	0.29b	0.12a
	Interior spruce	1.58a	0.22a	0.20a	0.72a	0.52a	0.12a

[1] In each year, means within columns followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 18 (each sample is a composite of three subsamples).

TABLE 23. Comparison of mean foliar nutrient concentrations between the main site preparation treatments in the first two growing seasons

Sampling time	Species	Nutrient concentrations (%)					
		N	P	S	K	Ca	Mg
1988	Windrow	1.42b[1]	0.23a	0.18b	0.76a	0.31a	0.12a
	Burn	1.50b	0.24a	0.19b	0.81a	0.29a	0.12a
	Spray & burn	1.73a	0.24a	0.22a	0.83a	0.36a	0.13a
1989	Windrow	1.56a	0.18a	0.18a	0.66b	0.39a	0.13a
	Burn	1.49a	0.18a	0.21a	0.70a	0.39a	0.13a
	Spray & burn	1.60a	0.19a	0.19a	0.69ab	0.44a	0.11a

[1] In each year, means within columns followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 12 (each sample is a composite of three subsamples).

TABLE 24. Comparison of mean foliar nutrient concentrations between disc-trenching treatments in the first two growing seasons

Sampling time	Species	Nutrient concentrations (%)					
		N	P	S	K	Ca	Mg
1988	Non-trenched	1.57a[1]	0.25a	0.21a	0.80a	0.31a	0.13a
	Disc-trenched	1.53a	0.23a	0.19a	0.80a	0.32a	0.12a
1989	Non-trenched	1.49b	0.18a	0.19a	0.64b	0.38a	0.12a
	Disc-trenched	1.61a	0.19a	0.20a	0.72a	0.43a	0.13a

[1] In each year, means within columns followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; n = 18 (each sample is a composite of three subsamples).

TABLE 25. Comparison of mean foliar nutrient concentrations between species and treatment regimes in the first two growing seasons following planting

		Lodgepole pine						Interior spruce					
		Windrow		Broadcast burn		Spray & burn		Windrow		Broadcast burn		Spray & burn	
	Year	N[1]	D	N	D	N	D	N	D	N	D	N	D
Total N	1988	1.64a[1]	1.54a	1.47a	1.91a	1.78a	1.79a	1.29a	1.23a	1.32a	1.30a	1.69a	1.65a
	1989	1.41a	1.64a	1.37a	1.59a	1.53a	1.51a	1.51a	1.60a	1.42a	1.59a	1.65a	1.73a
Total P	1988	0.22a	0.21a	0.20a	0.25a	0.21a	0.20a	0.23a	0.26a	0.25a	0.28a	0.26a	0.29a
	1989	0.16b	0.16b	0.14b	0.15b	0.16b	0.15b	0.20ab	0.22ab	0.22ab	0.20ab	0.22ab	0.24a
Total S	1988	0.21ab	0.20ab	0.19ab	0.25a	0.22ab	0.26a	0.15b	0.15b	0.16b	0.17ab	0.20ab	0.22ab
	1989	0.21a	0.20a	0.19a	0.21a	0.17a	0.18a	0.14a	0.20a	0.24a	0.20a	0.20a	0.22a
Total K	1988	0.70a	0.75a	0.79a	0.76a	0.80a	0.73a	0.78a	0.81a	0.65a	0.81a	0.84a	0.61a
	1989	0.57a	0.72a	0.62a	0.68a	0.61a	0.65a	0.68a	0.65a	0.69a	0.80a	0.65a	0.80a
Total Ca	1988	0.25b	0.24b	0.24b	0.23b	0.29ab	0.24b	0.37ab	0.37ab	0.29ab	0.39a	0.44a	0.46a
	1989	0.26b	0.30b	0.28b	0.25b	0.39b	0.29b	0.48ab	0.52ab	0.46ab	0.57ab	0.45ab	0.65a
Total Mg	1988	0.14a	0.11a	0.12a	0.12a	0.13a	0.12a	0.12a	0.14a	0.20a	0.14a	0.14a	0.13a
	1989	0.12a	0.13a	0.12a	0.12a	0.10a	0.12a	0.11a	0.14a	0.14a	0.14a	0.11a	0.11a

[1] For each variable, means within rows followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; $n = 3$ (each sample is a composite of three subsamples).

SILVICULTURAL IMPLICATIONS

The initial results of this study have several implications for the selection and application of site preparation treatments on partially cut backlog sites in the central interior of British Columbia. Because seedling growth results are only available for the first two growing seasons, however, the treatment efficacy interpretations should be considered tentative.

Treatment Efficacy

In the present study, few practical constraints were encountered in applying any of the treatments, but significant differences arose between treatments in vegetation regrowth, and in the growth of planted seedlings. Spray & burning resulted in less vegetation competition and better initial seedling performance than did broadcast burning and windrowing, and likely reduced the probability that further brushing treatments would be required to obtain a free-growing plantation. Although soil disturbance and nutrient losses due to windrowing were minimal in this study, there is probably greater risk of soil compaction and of greater nutrient losses associated with windrowing than with broadcast burning treatments, especially on sites with heavy debris loads. The initial results also suggest that disc-trenching may result in warmer soil temperatures and greater seedling volume growth, especially for lodgepole pine.

However, the feasibility and effectiveness of these treatments may be different on other partially cut backlog sites. Some site-specific factors that should be considered before treatments are prescribed for partially cut stands include the density and merchantability of the residual stand, and the amount and composition of understory vegetation. These in turn will affect the potential fuel load and vegetation competition. The fuel load may also be affected by salvage logging of merchantable stems. Of course, other site-specific factors such as adjacent timber values, proximity to water courses, and slope and soil texture also influence the prescription of burning, herbicide, and mechanical site preparation treatments in general.

Given the variability between sites in fuel load and vegetation competition, spray & burning with moderate forest floor consumption would probably be the most effective treatment for establishing planted seedlings on sites with significant potential for vegetation competition, or on sites where woody fuels are light or poorly distributed. Broadcast burning without spraying will be most effective on sites with a substantial slash load and low to moderate vegetation competition potential. Windrowing, if properly managed, may be an appropriate treatment for sites where it is necessary to reduce the slash load and where broadcast burning is not feasible. However, this study suggests that vegetation regrowth following windrowing will be substantial on brushy sites, particularly if aspen occurs in the residual stand, and that additional brushing treatments may be required.

This study did not examine all possible combinations of chemical, mechanical, and burning treatments, nor did it consider interactions with different sizes of planting stock. Other treatment regimes that provide plantable spots, reduce vegetation competition, and improve soil temperatures may also be effective for preparing partially cut backlog sites.

Treatment Costs

Treatment costs were not examined in this study because of the small size of the treatment units. They are best estimated from local experience. The survey data of Breadon (1988) provide typical costs and can be used to rank the relative cost of treatment regimes examined in this study: broadcast burn, windrow < spray & burn, windrow and disc-trench, broadcast burn and disc-trench < spray & burn and disc-trench. Initial costs increased with the number of entries made in a treatment regime, as did seedling volume, though seedling growth was significantly different between double entry regimes (e.g., spray & burn > windrow and disc-trench, and broadcast burn and disc-trench). However, if further brushing or replanting is required to obtain free-to-grow status following the windrow or the broadcast burn treatment, but not following the spray & burn treatment, the cost differential would be eliminated. This consideration also applies to the disc-trenched and non-trenched treatments.

Treatment Timing

Spraying of glyphosate before broadcast burning should be carried out early in the summer to allow time for the vegetation to be killed and dried, if burning is planned in the same year as spraying. Broadcast burning of whole-tree fuels, with or without prior spraying, should be carried out after at least the branches have cured to allow for maximum fire spread. Fine slash is cured by about the August following winter knockdown. Stems that are not completely severed during knockdown will dry even more slowly.

In this study, the volume of some competitive plants recovered to or exceeded pre-treatment levels within 2 years following treatment, even with intensive site preparation. Immediate planting with high quality stock on sites with significant vegetation competition is required to capture fully the short period of reduced vegetation competition and the site preparation investment.

REFERENCES

Ballard, T.M. and B.C. Hawkes. 1989. Effects of burning and mechanical site preparation on growth and nutrition of planted white spruce. Pac. For. Cent., Victoria, B.C. For. Can. Inf. Rep. BC-X-309.

B. C. Forest Service. 1976. Whole stem cubic metre volume equations and tables. Centimetre diameter class merchantable volume factors. Inventory Branch, Victoria, B.C.

Breadon, R.E. 1988. Survey of forest renewal programs in British Columbia. Part II: Northern Interior. FERIC Tech. Rep. TR-83.

Carter, R.E. and L.E. Lowe. 1986. Lateral variability of forest floor properties under second-growth Douglas-fir stands and the usefulness of composite sampling techniques. Can. J. For. Res. 16:1128–1132.

Frandsen, W.H. and K.C. Ryan. 1986. Soil moisture reduces belowground heat flux and soil temperatures under a burning fuel pile. Can. J. For. Res. 16:244–248.

Lawson, B.D. and B.C. Hawkes. 1989. Field evaluation of a moisture model for medium-sized logging slash. *In* Proc. 10th Conf. Fire and For. Meteor., April 17–21, 1989, Ottawa, Ont., pp. 247–257.

Lawson, B.D. and S.W. Taylor. 1986. Preliminary evaluation of prescribed fire impact relationships and predictors for spruce-balsam slash. *In* Proc. Fire Management Symp., Prince George, B. C., April 8–9, 1986. Sponsored by the Central Interior Fire Protection Committee, pp. 46–68.

Macadam, A.M. 1987. Effects of broadcast slash burning on fuels and soil chemical properties in the Sub-boreal Spruce Zone of central British Columbia. Can. J. For. Res. 17:1577–1584.

Quesnel, H.J. and L.M. Lavkulich. 1980. Nutrient variability of forest floors near Port Hardy, British Columbia, Canada. Can. J. Soil Sci. 69:565–573.

SAS Institute Inc. 1985. SAS User's Guide: statistics, Version 5 Edition. Cary, N.C.

Stocks, B.J, B.D. Lawson, M.E. Alexander, C.E. Van Wagner, R.S. McApline, T.J. Lynham, and D.E. Dube. 1989. The Canadian Forest Fire Danger Rating System: an overview. For. Chron. 65(6):450–457.

Taylor, S.W. and M.C. Feller. 1986. Initial effects of slashburning on the nutrient status of sub-boreal Spruce zone ecosystems. *In* Proc. Fire Management Symp., Prince George, B.C., April 8–9, 1986. Sponsored by the Central Interior Fire Protection Committee, pp 79–91.

Trowbridge, R., B. Hawkes, A. Macadam, and J. Parminter. 1986. Field handbook for prescribed fire assessments in British Columbia: logging slash fuels. B.C. Min. For. Victoria, B.C. Land Manage. Handb. No. 11. 63 p.

Van Wagner, C.E. 1977. A method of computing fine fuel moisture content throughout the diurnal cycle. Fisheries and Environ. Can., Petawawa For. Exp. Sta., Chalk River, Ont. Inf. Rep. PS-X-69.

Vasander, H. and T. Lindholm. 1985. Fire intensities and surface temperatures during prescribed burning. Silva Fennica 19:1–15.

APPENDIX 1. Burning conditions on the day of ignition

Time (LST)	Temp. (°C)	RH (%)	Wind speed (km/h)[a]	FWI System Values[b]					
				FFMC	DMC	DC	ISI	BUI	FWI
12:00	21.3	32	5.7	90	25	235	6	40	14
16:00	21.0	30	13.8	91	—	—	10	—	20
17:00	20.0	28	14.8	90	—	—	11	—	21
18:00	18.0	32	11.6	90	—	—	8	—	17
19:00	14.1	43	2.6	89	—	—	4	—	10

[a] 10-minute average.
[b] Codes and indices of the Canadian Forest Fire Weather Index System (Stocks *et al.* 1989). Values at 12:00 are daily standard values, and for 16:00–19:00 are diurnally adjusted hourly values calculated with an unpublished computer program prepared at Petawawa National Forestry Institute, modified after Van Wagner (1977).

APPENDIX 2. Seedling morphological characteristics and RGC values at the time of planting

	RGC[a]	Height (cm)	Diameter (mm)	Mass (g)				Shoot/root
				Root	Stem	Foliage	Total	
Interior spruce, stock type 1-0 PSB 313, seedlot 4285[b]								
Mean[c]	2.6	23.0	2.9	0.567	0.897	0.899	2.362	3.16
Max.	4	35.1	3.4	1.434	1.646	1.134	3.183	
Min.	1	10.0	2.2	0.266	0.233	0.644	1.474	
Lodgepole pine, stock type 1-0 PSB 211, seedlot 2196[b]								
Mean	4.9	16.9	2.7	0.480	0.372	0.405	1.251	1.62
Max.	5	26.8	3.8	0.827	0.674	0.794	1.536	
Min.	4	6.2	2.1	0.223	0.193	0.241	0.942	

[a] Root Growth Capacity (carried out by staff of the B.C. Ministry of Forests, Red Rock Research Centre).
[b] Grown at the Industrial Forest Service nursery in Prince George and lifted in November 1987.
[c] Mean of 50 seedlings for all variables except RGC which is mean of 16 seedlings.

APPENDIX 3. Mean relative densities (oven dry weight/air dry volume) of woody fuel components

Diameter class (cm)	n[a]	Species/condition class			
		Subalpine fir	Interior spruce	Unidentified	
				Sound	Decayed
0.0–0.5	25	0.60	0.59	0.58 (9)	—
0.6–1.0	15	0.61	0.60	—	—
1.1–3.0	15	0.59	0.56	0.70	—
3.1–5.0	15	0.49	0.47	0.54 (3)	—
5.1–7.0	15	0.45	0.43	0.40 (3)	—
≥ 7.1	15	0.39	0.41	0.38	0.26 (7)

[a] No. of samples represented by each mean, except for those which are given in parentheses.

APPENDIX 4. Comparison of mean mineral soil bulk densities before and 1 year following disc-trenching (0–15 cm depth)

	Non-trenched	Disc-trenched
Pre-[1]	0.764a	0.760a
Post-	0.745a	0.879b
Change[2]	-0.018	0.119*

[1] Means within rows followed by the same letter are not significantly different at $p < 0.05$ according to t-tests; $n = 36$.

[2] * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; $n = 18$ (each observation is the mean of two subsamples).

APPENDIX 5. Comparison of mean mineral soil bulk densities before and 1 year following treatment by site preparation regime (0–15 cm depth)

	Windrow		Broadcast burn		Spray & burn	
	N[1]	D	N	D	N	D
Pre-[2]	0.803a	0.856a	0.733a	0.708a	0.756a	0.717a
Post-	0.800a	0.860a	0.798a	0.987a	0.638a	0.789a
Change[3]	-0.003	0.004	0.065	0.275**	-0.117	0.072

[1] N = non-trenched; D = disc-trenched.

[2] Means within rows followed by the same letter are not significantly different at $p < 0.05$ according to Student-Neuman-Keuls multiple range tests; $n = 12$.

[3] * and ** indicate that the change is significant at $p < 0.05$ and $p < 0.01$, respectively, according to a least squares means test; $n = 3$ (each observation is the mean of two subsamples).